

BONE MINERAL MEASUREMENT USING DUAL  
ENERGY X-RAY DENSITOMETRY

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## ABSTRACT

Bone mineral measurements before and after space missions have shown that weightlessness greatly accelerates bone demineralization. Bone mineral losses as high as 1 to 3% per month have been reported. Highly precise instrumentation is required to monitor this loss and thereby test the efficacy of treatment. During the last year, a significant improvement has been made in Dual-Photon Absorptiometry by replacing the radioactive source with an x-ray tube. Advantages of this system include: better precision, lower patient dose, better spacial resolution, and shorter scan times. The high precision and low radiation dose of this technique will allow detection of bone mineral changes of less than 1% with measurements conducted directly at the sites of interest. This will allow the required bone mineral studies to be completed in a shorter time and with greater confidence.

## INTRODUCTION

It is well known that weight bearing bones demineralize if not subjected to mechanical stress. While the mechanism of this bone loss is not understood, it is clear that the reduced bone mineral density impairs the mechanical integrity of the skeletal system and may result in bone fractures. X-ray evidence of this demineralization is present at about 12 weeks in patients immobilized by major fractures or paralysis. Manned space flights have shown that extended periods of weightlessness have a similar effect. In US space flights lasting as long as 3 months, loss of bone mineral has not impaired the functional capabilities of astronauts. However, the prospect of extended and repeated flights requires additional bone mineral research to protect the health and insure the performance of space crews.

During the last year, a significant improvement has been made made in Dual Photon Absorptiometry bone mineral measurement by replacing the radioactive source with an x-ray tube. Many factors motivate this change. The greater output flux of the x-ray tube permits shorter scan times and better precision. The smaller focal spot permits better beam collimation which results in better spatial resolution and lower patient dose. In addition, elimination of the radioactive material simplifies licensing and eliminates the need for yearly source replacement. These developments have been commercialized to monitor bone disorders in the general public. This paper discusses the operating principles of this new instrumentation and how it can be applied to manned space flight.

## BONE DEMINERALIZATION

A gradual loss of bone mineral is normal throughout adulthood. It has been well established that bone mineral density decreases about 1% per year with variation depending on the site examined (Krolner and Pors Nielsen, 1982; Riggs et al, 1982). Many mechanisms are responsible for accelerated

bone loss beyond this natural ageing process. Bone demineralization is a significant health problem for post menopausal women. In the United States, osteoporosis affects some 15 to 20 million persons, and results in more than 1 million fractures annually. The lifetime risk of a hip fracture to a female in the United States is about 15%, a similar risk as for breast cancer. Almost 20% of these fracture patients die within six months, and it has been estimated that 40% of the survivors do not return to the independence of their pre-fracture life-style.

While osteoporosis is a significant problem to the general public, it is an even greater problem to manned space flight. Bone mineral measurements before and after extended space missions have shown that weightlessness greatly accelerates bone demineralization. Bone mineral losses as high as 1 to 3% per month have been measured (Anderson and Cohn, 1985). At this rate of reduction, bone fractures could be expected in as little as 1-2 years. After returning to a gravitational environment, this bone mineral loss is reversed and at least some of the damage is repaired. Whether or not the bone mineral is restored to a pre-space flight level is not clear. Measurements on the Skylab astronauts five years after their flights were lower than before the flights and lower than in controls (Tilton et al, 1980).

## DUAL PHOTON ABSORPTIOMETRY

Drug, diet, and exercise therapies have been suggested to reduce bone loss. A critical part of any therapy program will be the ability to make highly precise bone mineral measurements. Precision, or the ability to make repeatable measurements, is necessary to detect the small changes in bone mineral that occur over a short period of time. In past experiments, the imprecise measurements techniques have yielded error bars nearly as large as the results trying to be measured. The recently developed technique of X-Ray Dual-Photon Absorptiometry (DPA) has been demonstrated to provide better than 1% precision on measurements of the spine and the hip. These are the preferred measurement sites because they are the most common sites to be fractured as a result of low bone mineral content.

Single Photon Absorptiometry (SPA), the predecessor of DPA, measures bone mineral content by passing a monochromatic beam of gamma rays through the patient. The measured gamma ray attenuation can then be related to the amount of bone mineral that the beam passes through. The significant problem with SPA is that there is no effective way of separating attenuation due to bone from attenuation due to soft tissue. This leads to errors in accuracy and precision.

Dual Photon Absorptiometry was developed to better separate tissue from bone. The instrumentation is similar to SPA, except a radionuclide is used that emits photons at two distinct energy levels. The most commonly used radioisotope is Gadolinium-153, which emits a group of gamma rays at about 44 Kev and another group at about 100 Kev. Bone attenuates the lower energy photons much more than the higher energy ones. Soft tissue, on the other hand, attenuates both energy levels about an equal amount. This differential attenuation allows the separation of bone from soft tissue. Two equations can be written using the measured attenuation at the two energies. From these two equations, the two unknowns can be found, namely the amount of soft tissue and the amount of bone mineral.

Several methods have been suggested as to how to use an x-ray tube to perform DPA. One approach is to shape the x-ray spectrum by use of a rare

earth filter. The beam exiting an x-ray tube contains x-rays of widely varying energies. Fig. 1. shows the spectrum of two x-ray beams after passing through filters containing rare earth elements. The high absorption of the rare earth K-edges have removed x-rays with energies near the center of the spectrum. This results in two clearly defined energy peaks. These two energy peaks can then be used in the same manner as the radionuclide scanners which use the two energy peaks of Gadolinium-153. The broken line in Fig. 1. was obtained for a Samarium filter at 90 KV x-ray tube operation, while the unbroken line is for Cerium at 80 KV. These two sets of operating parameters have both been used in DPA systems.

## SYSTEM PERFORMANCE

In 1988, Lunar Radiation completed development of the Dual Photon X-ray (DPX) system. The DPX system is capable of whole body bone mineral scans as well as localized scans such as the spine and hip. Spine scans take approximately 4 minutes and require 1 mR patient dose. Spatial resolution is approximately 2 mm.

Several thousand scans on spine phantoms have shown a DPX precision of about 0.5%. Monte Carlo simulations have shown that this precision is limited by quantum statistics of the detected x-rays, implying that better precision can not be obtained without increasing the radiation dose. Several *in vivo* spine studies have been completed on the DPX. As shown in Fig. 2, a normal 25 year old male volunteer was scanned daily over a period of 3 weeks. The measured precision of this study is 0.8%, which is typical of other *in vivo* studies conducted. It should be noted that no drift is observable in the data over the three week measurement period. It should also be noted that the radiation dose received by the volunteer for the entire study was no more than for a standard chest x-ray. This combination of high precision and low dose allows repetitive measurements to detect bone mineral changes as low as 1 percent.

## CONCLUSION

The fundamental processes of bone demineralization during weightlessness are poorly understood. Additional studies are required to insure the health and effectiveness of space flight crews. X-ray instrumentation developed during the last year has significantly improved the ability to measure bone mineral, and the resulting integrity of the skeletal system. The high precision and low radiation dose of this technique allows detection of bone mineral changes of less than 1% with examinations conducted directly at the anatomic sites of interest. This will allow the required bone mineral studies to be completed in a shorter time and with greater confidence.

## REFERENCES

- Anderson, S. and S. Cohn. Bone demineralization during space flight, The Physiologist, vol 28, No 4, 212-217, 1985
- Krolner, B. and S. Pors Nielsen. Bone mineral content of the Lumbar spine in normal and osteoporotic women, Clinical Science, 62, 329-336, 1982.

Riggs, B et al. Differential changes in the bone mineral density of the appendicular and the axial skeleton with ageing. Relationship to spinal osteoporosis, *Journal of Clinical Investigations*, 67, 328-335, 1981.

Tilton, F., J. Degioanni, V. Schneider. Long term follow up of Skylab bone demineralization, *Aviat. Space Environ. Med.*, 51, 1209-1213, 1980

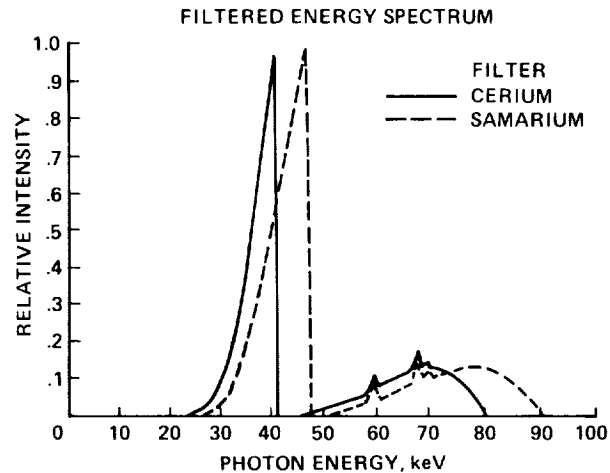


Fig. 1. Energy spectrum produced by rare earth filtration.

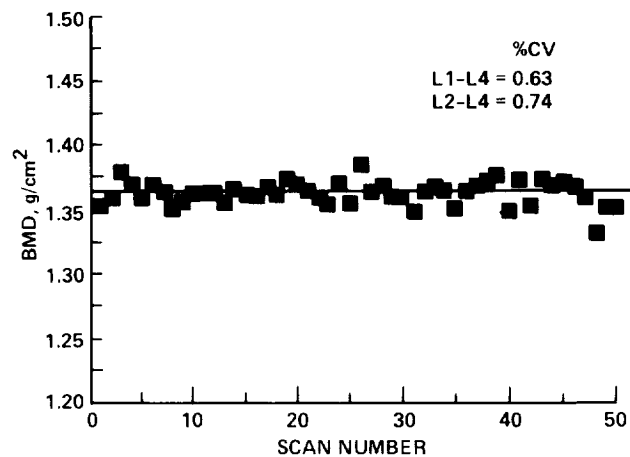


Fig. 2. Measured in-vivo precision of the DPX system.

## **PRESENTATION VIEWGRAPHS**

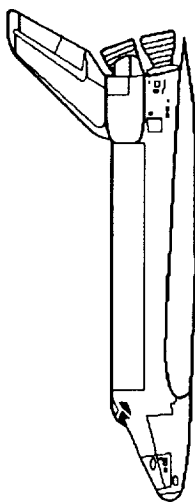
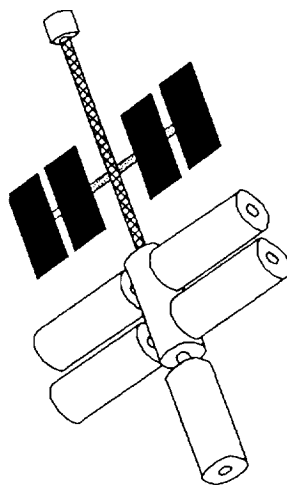




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## INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

### ABSTRACT

Proper instrumentation is key to the success of a spaceflight experiment. Development of proper instrumentation for a microgravity environment, especially under the constraints imposed by a manned vehicle, is a more difficult task than might be imagined. This presentation discusses the definition, design, development and testing of instrumentation, considers the requirements, interfaces and scope of instrumentation, and provides anecdotes gleaned by the Space Life Sciences Payloads Office from simulations and flights.



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INSTRUMENTATION: THE ADDITIONAL FACTOR THAT AFFECTS MICROGRAVITY BIOSCIENCE EXPERIMENTS

SUB-TITLE: MURPHY WAS AN OPTIMIST!

#### INSTRUMENTATION:

Instrumentation is defined here broadly as all equipment required to support the experiment. When designing instrumentation, we (and hopefully the PI) consider **requirements, interfaces and scope of instrumentation**. While these are highly interactive considerations (PAYLOAD DEVELOPMENT VIEWGRAPH, VERIFICATION VIEWGRAPH), for the purposes of this presentation, they are discussed as discrete entities.

#### REQUIREMENTS:

While ground-based studies generally consider advertised (or needed) capability, availability and cost, we have additional requirements, and strongly consider (in addition to the usual science requirements) **reliability, training and imposed requirements**. Interaction of these in the space environment is much more extensive and apparent than in ground-based studies.

#### SCIENCE REQUIREMENTS:

Science requirements must consider not only the type of experiment to be performed, but the conditions (environment) under which it is performed, the number of subjects, and who is performing it (crew, unattended, unmanned). These aspects are generally well considered during the payload development process, but when they are not, major perturbations usually result. *Anecdotes:*

- Squirrel Monkey Feeder - Switch inadvertently disabled during S/L shutdown. No indicator.
- Urine Monitoring System - Airflow levels insufficient to control streams/boluses of water.
- Tissue Shipment - Properly packaged shipment went astray long enough for ice to "melt".
- Cell Culture System - Piston containment exerted too much pressure on cells.





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INSTRUMENTATION (Cont.):  
REQUIREMENTS (Cont.):

**RELIABILITY REQUIREMENTS:**

No, you can't fix it at your bench! Reliability requirements consider not only whether the unit will perform the designated function, but also whether the unit will endanger other operations and the number of flights the unit is designed for. The review process for instruments/payloads is designed to help assure that nothing is missed. When something is, then - *Anecdotes*:

- Sea Urchin Handle - Hardware flimsy, poorly marked and incompletely tested. Limited training of crew for "carry-on". Result - Handle turned too far and equipment damaged; no results.
- Drop Dynamics Module - Failed on start-up. Crew spent most of mission on repair.
- Tissue Shipment - Properly packaged shipment went astray long enough for ice to "melt".

**IMPOSED REQUIREMENTS:**

Imposed requirements are generally of a nature to protect the crew, vehicle and other experiments. Violations of this nature (cleanliness, sharp edges, safety, ease of function, forbidden materials, etc.) prevent you from flying when discovered before launch. When discovered later, they are often major embarrassments. *Anecdotes*:

- Particulates on SL-3 - Animals produced more particulates, and air stream failed to control.
- Urine Monitoring System - See Science Requirements section.
- Monkey Door - Perforated door replaced with solid. Designer used same part number. Result - Door replaced by back-up, perforated door, and solemn assurance to Mission Manager violated.



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INSTRUMENTATION (Cont.):  
REQUIREMENTS (Cont.):

**TRAINING REQUIREMENTS:**

Generally, you can't perform your own experiment. A surrogate (crew) has to do it. This means that the crewman must be as well-trained, or better trained than you. The best developed hardware is no better than the person operating it. Generally, sufficient training sessions are provided (MISSION APPROACH VIEWGRAPH). *Anecdotes:*

- Very Wide Field Camera - Scientific Airlock handle damaged; no results.
- Sea Urchin Handle - See Reliability Requirements section.
- Autogenic Feedback Training - Crew not sufficiently convinced of value; limited data.

**INTERFACES:**

Interfaces are defined here more broadly than those usually seen. For the purposes of this presentation, interfaces will be identified as **defined, constrained and controlled**. To use the current vernacular, if you don't interface, you are not part of the group (that flies).

**DEFINED INTERFACES:**

Defined interfaces are those you will find in the vehicle handbook (Spacelab Payload Accommodations Handbook). They include data, rack, power buss, telemetry, etc. interfaces. They are usually quite definitive and explicit, rarely contradictory, and often correct. *Anecdotes:*

- Rack Interfaces - Hand made, so therefore requires hand-fitting or slotted holes.
- Document Conflicts - What to do when you find them. and *when you don't*.



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INSTRUMENTATION (Cont.):  
INTERFACES (Cont.):

**CONSTRAINED INTERFACES:**

Constrained interfaces are most often referred to as resources (power, weight, size, volume, crew time, data handling capability, etc.). If you do not consider them as constrained interfaces, you could be in trouble when developing hardware. In addition, they are often jello-like in spite of signed interface agreements. *Anecdotes:*

- Autogenic Feedback Training - Bulky waistpack limited usefulness; crew time requirements limited participation.
- ATMOS Vacuum Leak - SL-3 expts asked to give up/juggle operating time for ASTRO data.
- SLS-1/2 - Experiments de-manifested due to a combination of growth and oversubscription.

**CONTROLLED INTERFACES:**

Controlled interfaces come with the vehicle and include cabin pressure/temperature/humidity, gas composition, orientation, g-forces, access to vehicle, etc. They are usually very reliable until you rely on them. Then all sorts of interesting things happen. *Anecdotes:*

- Research Animal Holding Facility, Late Access - Mid-aisle transporter plus entry gantry became mid-aisle transporter plus Module Vertical Access Kit became mid-deck transporter with crew maneuver through tunnel became rack-mounted Module with MVAK servicing, and then they wanted to change from oxygen to nitrogen in Spacelab for better fire control.
- Ant Colony - Student Space Involvement Program. Ants perished on pad.
- Web Building - SSIP; Low humidity in S/L required crew to hand-feed spiders.
- RAHF - Low humidity in S/L could have contributed to particulate problem.



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INSTRUMENTATION (Cont.):

**SCOPE OF INSTRUMENTATION:**

Scope of instrumentation can be delineated as **not enough, too much, wrong kind and just right.** As with Science Requirements, the scope of instrumentation is often dictated by the type of experiment, the environment, sample size, and who is performing it (crew, unattended, unmanned). Included in this section would also be telepresence operations.

**NOT ENOUGH INSTRUMENTATION:**

Most reporting from Spacelab is of the negative/confirmation variety. For the sake of the experiment, you want the experiment to provide the crew with sufficient information to determine if it is proceeding properly. For the sake of your psyche, you want sufficient information to make intelligent judgements on the progress of the experiment. However, a balance must be achieved between critical information, resources and extremely competent crew. *Anecdotes:*

- RAHF Monkey Feeder - See Science Requirements section. No indicator on ground, either.
- Problem Solving - No information, no solutions.

**TOO MUCH INSTRUMENTATION:**

Over-instrumented equipment increases probability of failure and over-utilizes valuable resources. Over-instrumented specimens can also be deadly with respect to the information obtained and with respect to the specimen. *Anecdotes:*

- RHESUS Project - Concern about loops and negative feed-back.
- Biosatellite III - Over-instrumentation of Bonnie could have been a factor.



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INSTRUMENTATION (Cont.):  
SCOPE OF INSTRUMENTATION (Cont.):

**WRONG KIND OF INSTRUMENTATION:**

Considerable care must be given to the choice of instrumentation with regard to proper science support, with regard to crew and human factors considerations, and with regard to function in the unique environment of microgravity. Equipment which performs beautifully for you in ground-based experiments can be worthless in Spacelab. *Anecdotes:*

- Autogenic Feedback Training - Pack was bulky and got in the way; was not worn as scheduled.
- Cell Culture System - Cells adhered poorly; fluid shear displaced cells.
- KC-135 Flights - Provides ability to validate microgravity concepts with short-duration parabolas.

**PROPER INSTRUMENTATION:**

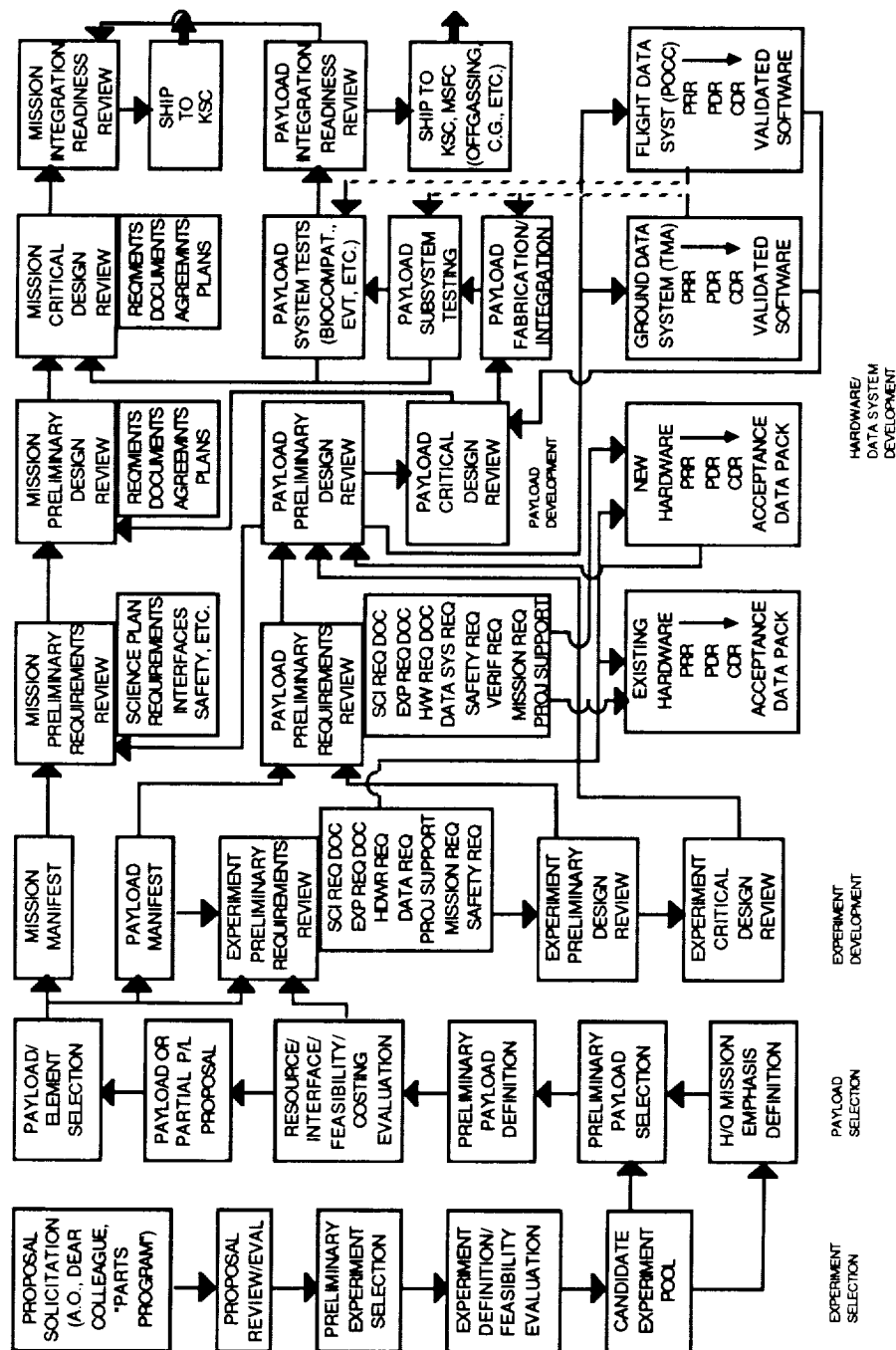
Non-existent state we all strive to obtain. *Anecdotes:*

- Future Hardware?



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## PAYLOAD DEVELOPMENT APPROACH AT AMES RESEARCH CENTER





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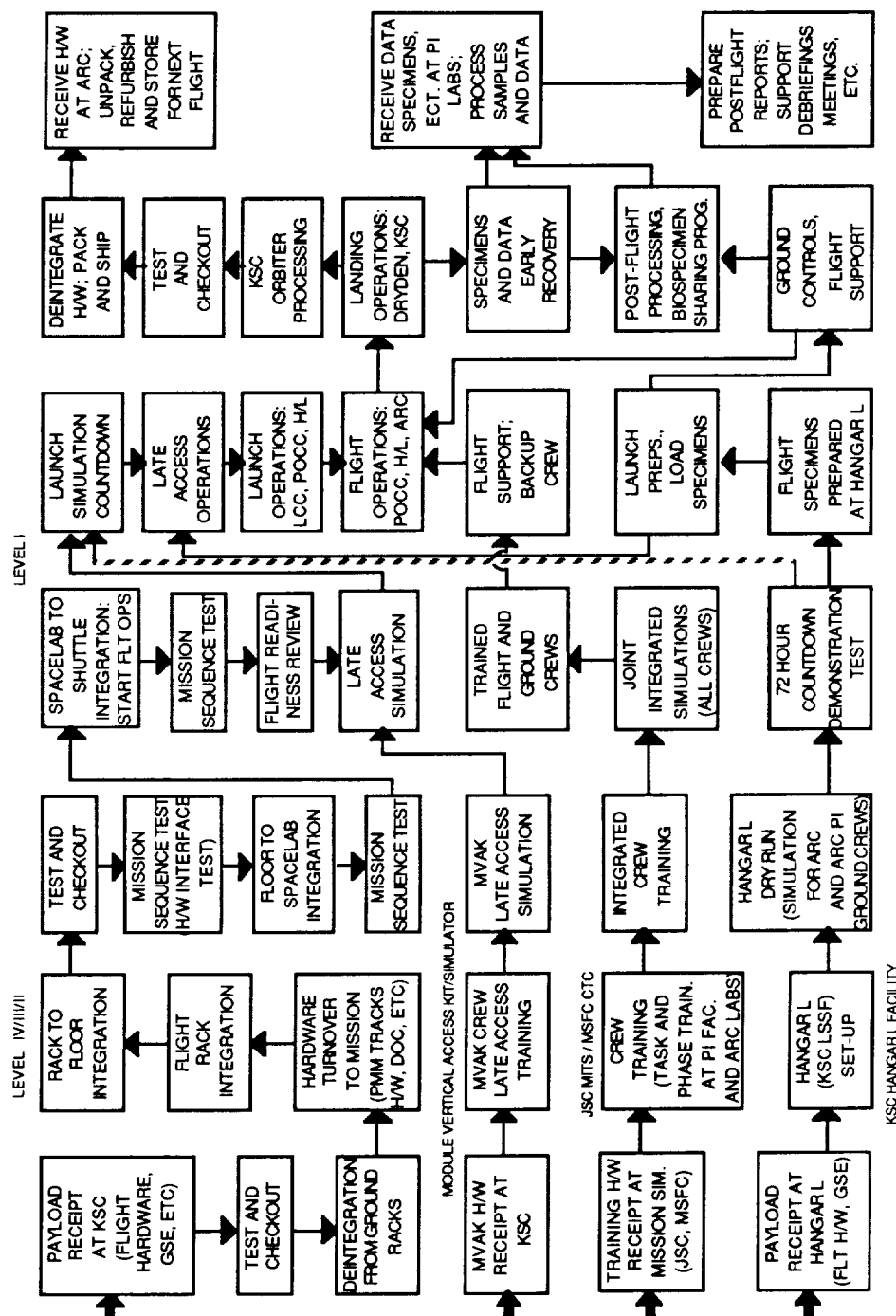
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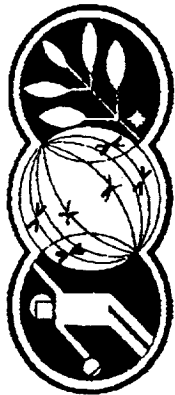
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MISSION APPROACH FOR AMES RESEARCH CENTER PAYLOADS





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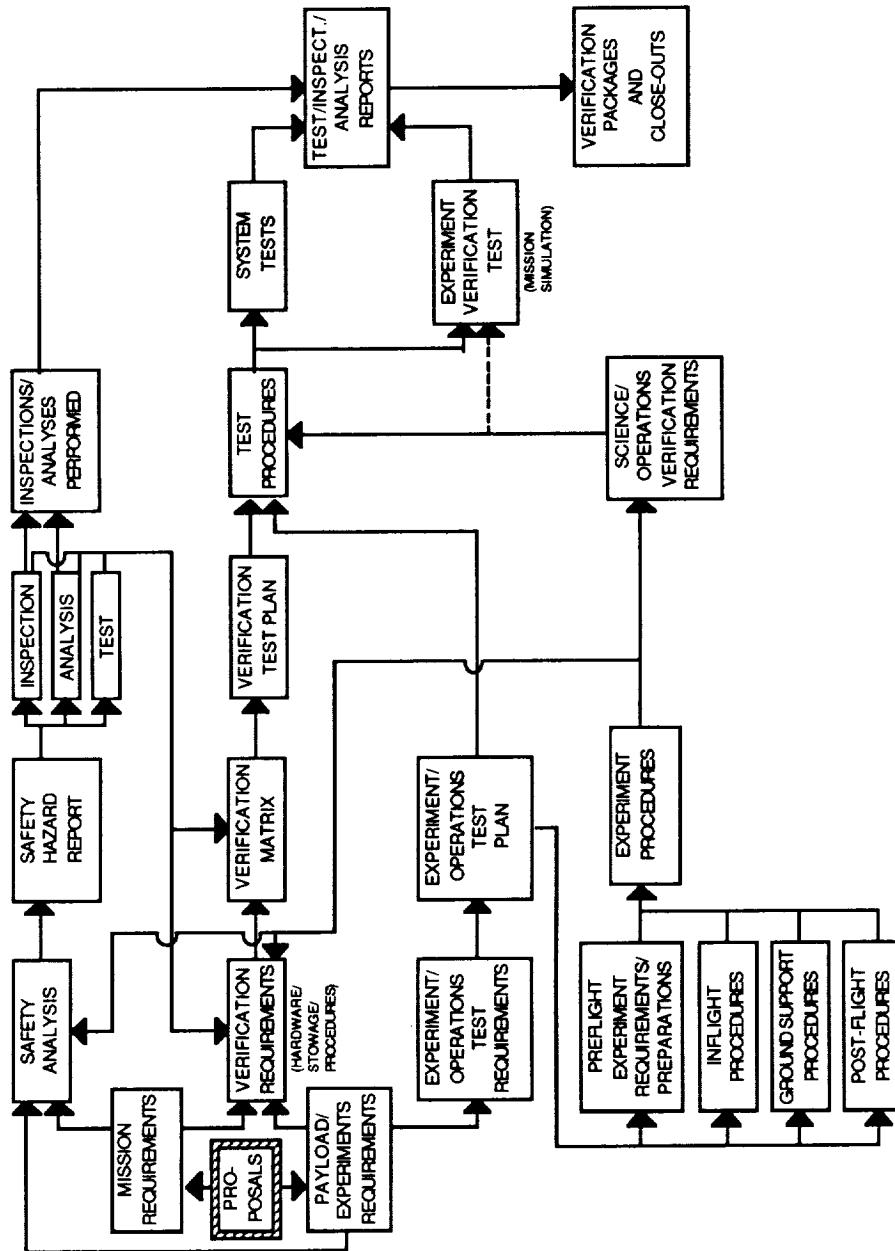
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**RODNEY W. BALLARD/SP**

**CELLS IN SPACE-II CONFERENCE**

**11/2/88**

**LIMITATIONS ON SCIENCE  
DUE TO  
MISSION CONSTRAINTS**

**RODNEY W. BALLARD, Ph.D.**

**NASA ARC**

## **LATE/EARLY ACCESS**

- LATE LOADING --
  - 18 TO 24 HOURS PRIOR TO LAUNCH
  - THIS MEANS AS MUCH AS 54 HOURS FROM LOADING TO SPACELAB ACCESS
- EARLY UNLOADING
  - 2 TO 4 HOURS AFTER LANDING
  - STS IS TALKING 24 HOURS FOR SAFETY REASONS
- ASCENT AND DESCENT
  - DATA ACQUISITION IS ALMOST IMPOSSIBLE
  - ELECTRICAL POWER IS VERY LIMITED
  - NO ACCESS POSSIBLE

## CREW TIME

- LITTLE CREW TIME IS AVAILABLE FOR AN INDIVIDUAL EXPERIMENT
  - SELF-CONTAINED AND AUTOMATED EXPERIMENTS ARE ENCOURAGED
  - TELESCIENCE MAY OR MAY NOT BE AN ANSWER
- CREW MEMBER MAY NOT BE A SPECIALIST IN YOUR DISCIPLINE
  - CREW TRAINING IS ESSENTIAL
  - SIMPLE AND FOOLPROOF PROCEDURES YIELD THE BEST RESULTS
  - IF A HARDWARE FAILURE OCCURS, SIMPLE HARDWARE IS EASIEST TO FIX
- SAFETY IN SPACELAB IS ALL IMPORTANT
  - RADIOISOTOPES AND OTHER TOXIC MATERIALS MUST BE TRIPLE CONTAINED
  - SPECIAL FAILURE MODE ANALYSIS MAY BE REQUIRED
  - LIMITS ON TOXIC MATERIALS REGARDLESS OF CONTAINMENT

## **MISSION DURATION**

- MISSION LENGTH SHOULD MATCH THE SCIENCE OBJECTIVES
  - STS MISSIONS WILL BE FROM 4 - 16 DAYS
  - \* ALL MID DECK OPPORTUNITIES ARE NOT THE SAME!
- SPACELAB MISSIONS ARE TENDING TOWARD LONGER DURATIONS
  - \* THIS IS GOOD FOR CREW TIME, BUT NOT IF HARDWARE, CONSUMABLES OR SPECIMENS ARE NOT DESIGNED FOR THE MISSION LENGTH
- LONGER MISSIONS MEAN EVEN MORE POWER RESTRAINTS
  - \* EVEN SHORT PERIODS OF HEAVY POWER MAY NOT BE ACCOMMODATED

## **GENERAL CONSTRAINTS**

- LIMITED OPPORTUNITY FOR REPEAT EXPERIMENTS
- WEIGHT AND VOLUME RESTRICTIONS MEAN THAT THE LARGER THE ORGANISM THE SMALLER THE "N"
- BIOINSTRUMENTATION
  - IMPLANTS MUST BE DEMONSTRATED FOR SEVERAL MONTHS NOT JUST DURATION OF MISSION
  - DATA TRANSFER AND PROCESSING MAY BE LIMITING
  - WITH LIMITED NUMBERS OF SPECIMENS, HARDWARE FAILURES ARE MAGNIFIED





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CELLS II:

MISSION

REQUIREMENTS AND CONSTRAINTS

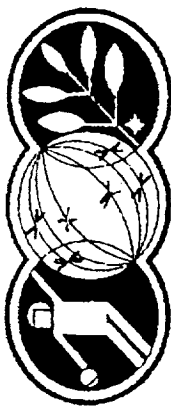
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## MISSION CONSTRAINTS ON HARDWARE DESIGN

### - ABSTRACT -

A summary of Mission requirements is presented, including physical, safety and operational constraints. A list of documentation and formal reviews is presented. The effects of hardware and operational changes are described.





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MISSION CONSTRAINTS ON HARDWARE DESIGN

In addition to the scientific and performance requirements imposed by the Principal Investigator the hardware must meet various Mission requirements.

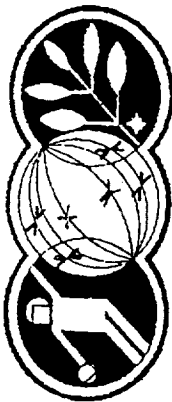
These mission requirements are imposed to protect the crew, the orbiter and other flight experiments on the same mission.

In addition to requirements imposed on the flight hardware, similar and in some cases identical requirements are imposed for hardware used in flight concurrent ground studies (Hangar L) and on ground support hardware used in conjunction with flight hardware.

This is by no means a complete listing of mission requirements, it is intended to give the experiment / hardware developer an inkling of what to expect. Many capable people are available to the Scientist and Hardware Developer to assist in the design, fabrication and documentation process necessary to qualify and fly experiment hardware.



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I PHYSICAL CONSTRAINTS

A. SIZE, SHAPE, VOLUME, MASS DISTRIBUTION

- \* MUST FIT INTO ASSIGNED ENVELOPE
  - SINGLE OR DOUBLE RACK
  - MID-DECK LOCKER
  - STOWAGE LOCKER
  - ETC.

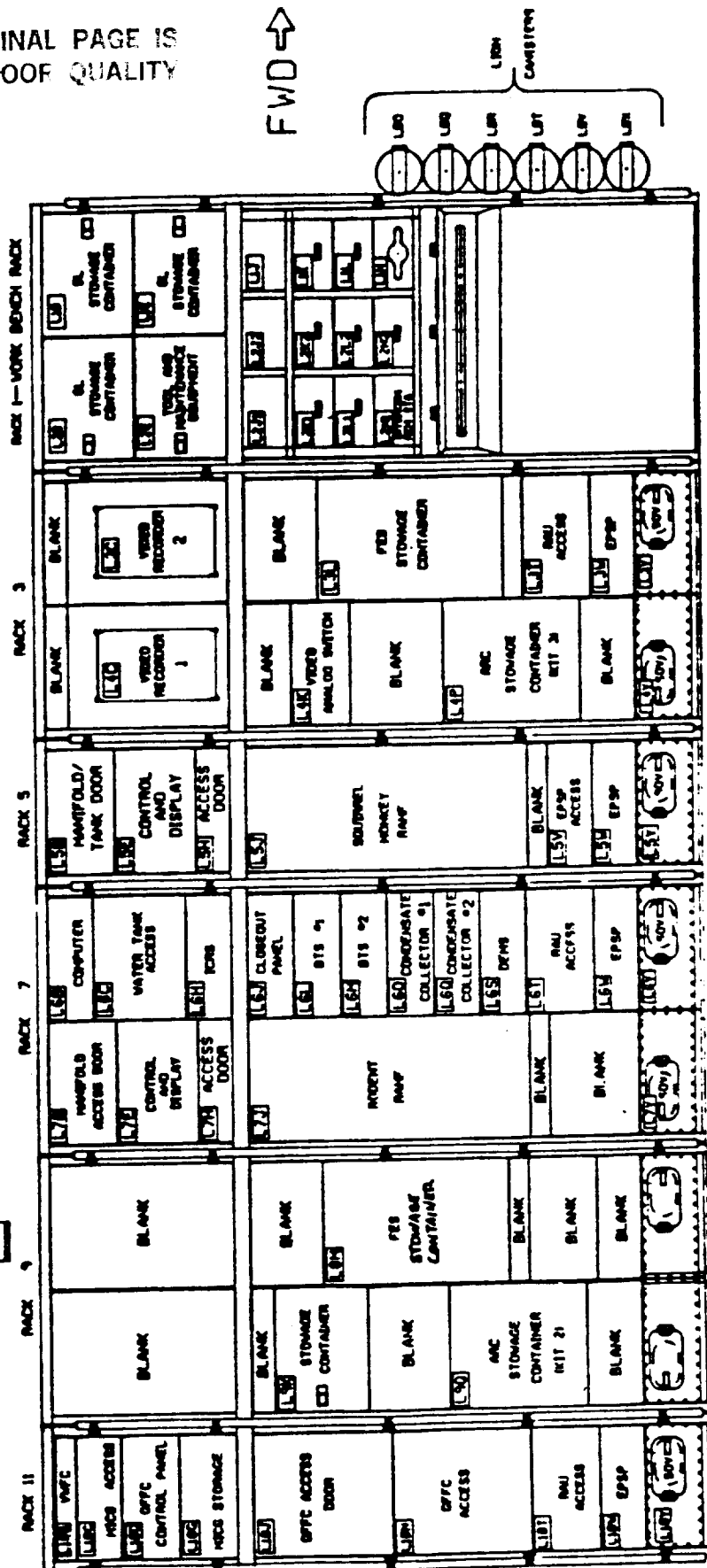
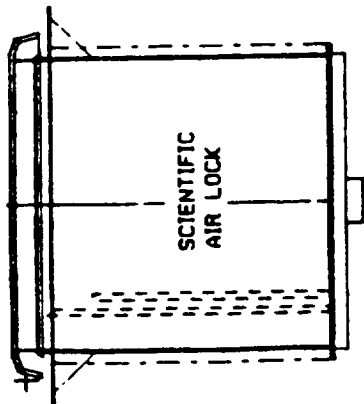
B. MASS LIMITS

- \* RACK STRUCTURAL LIMITATIONS
- \* RACK DICTATED LIMITS FOR LOCATION OF CENTER  
OF GRAVITY

FWD ↑

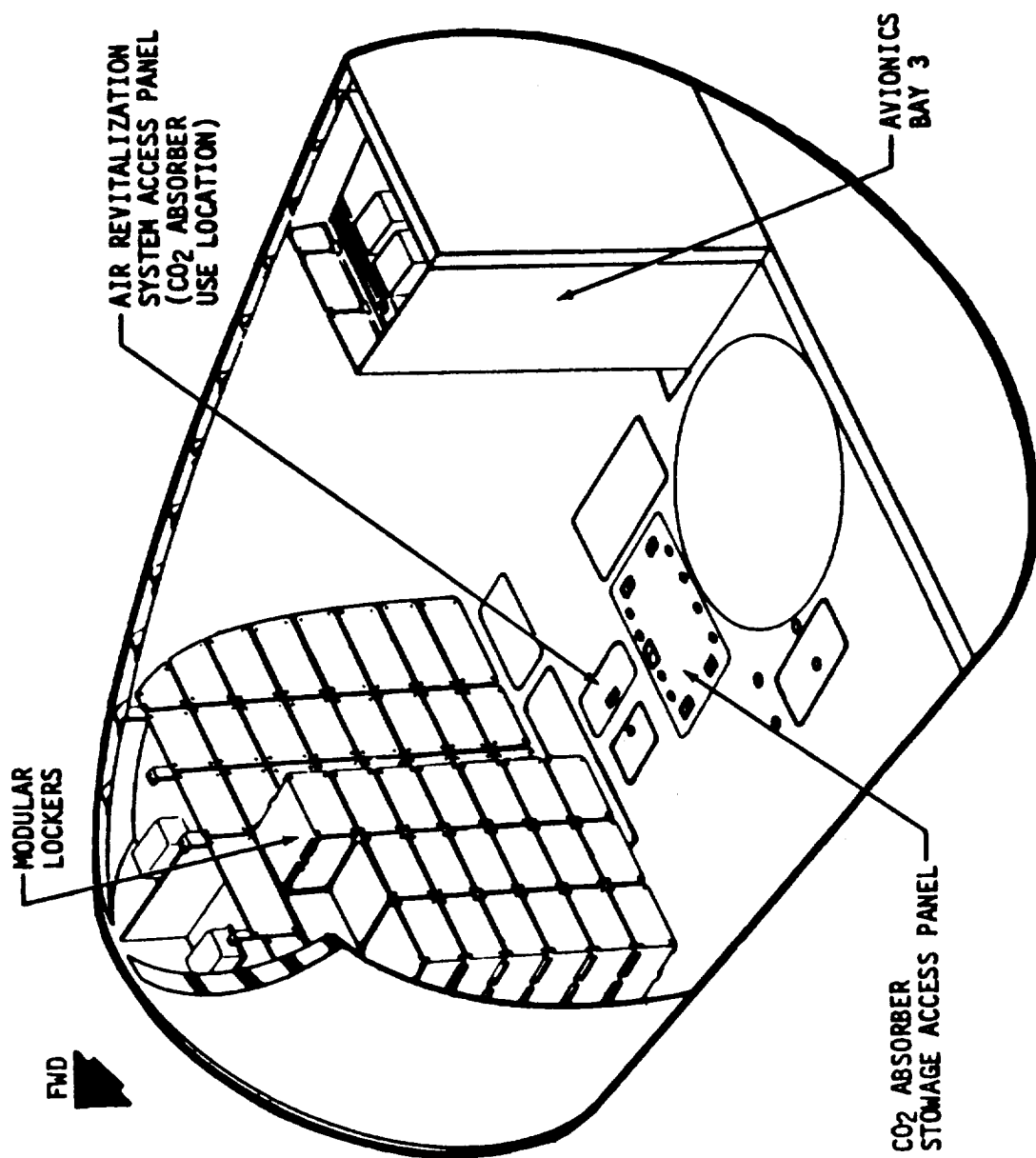
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## OVERHEAD STOWAGE CONTAINERS



PORT SIDE





MIDDECK LOCKERS



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### C. HARDWARE STRUCTURAL CAPABILITY

- \* HARDWARE MUST BE CAPABLE OF WITHSTANDING THE LAUNCH AND RECOVERY LOADS.
  - ANALYSIS AND TEST DATA MUST DEMONSTRATE THAT THE AS-BUILT HARDWARE'S STRUCTURAL CAPABILITY EXCEEDS THESE LOADS BY A POSITIVE MARGIN
- \* THE HARDWARE MUST BE CAPABLE OF WITHSTANDING ALL LOADS THAT MAY BE IMPOSED DURING TRANSPORT, OPERATION, ASSEMBLY, DISASSEMBLY AND STOWAGE
  - THE HARDWARE MUST BE CAPABLE OF WITHSTANDING ALL CREW-APPLIED LOADS.
    - LOADS EXPERIENCED DURING HARDWARE USE
    - INADVERTENTLY IMPOSED LOADS
      - "KICK-OFF" LOADS
      - HARDWARE FIXED TO IMMOVABLE STRUCTURES
  - LOADS IMPOSED BY TETHERS DURING ORBITER ACCELERATION / DECELERATION



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C. STRUCTURAL CAPABILITY (continued)

- \* THE HARDWARE MUST BE CAPABLE OF WITHSTANDING THE PRESSURES DEVELOPED WITHIN THE HARDWARE DUE TO SPACELAB DEPRESSURIZATION / REPRESSURIZATION
  - DEPRESSURIZATION / REPRESSURIZATION CURVE IS SPECIFIED IN THE SPACELAB ACCOMMODATIONS HANDBOOK (SPAH)

II SAFETY

A. FLAMMABILITY, FLAME PROPAGATION, COMBUSTION PRODUCTS  
TOXICITY

- \* OFF-GASSING CONSTITUENTS

B. CONTAMINATION OF THE SPACELAB ENVIRONMENT

- \* LIQUIDS
  - FIXATIVES
  - GROWTH MEDIA
  - EXPERIMENT LIQUID WASTE
- \* SOLIDS, PARTICULATE MATTER
  - SOIL
  - FOOD BAR PARTICLES
  - EXPERIMENT SOLID WASTE



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<b>NAME/ORG:</b> LASHBROOK / SLSP0	<b>TITLE:</b> CELLS II - MISSION REQUIREMENTS AND CONSTRAINTS ON EXPERIMENT HARDWARE	<b>DATE:</b> 10/31 - 11/4/88
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SAFETY (continued)

C. BIOHAZARDS

- \* RADIOACTIVE TRACERS
- \* CARCINOGENS
- \* TOXIC SUBSTANCES

D. ELECTRICAL SHOCK

- \* ANALYSIS AND TEST DATA MUST DEMONSTRATE THE ELECTRICAL SAFETY OF THE HARDWARE

E. EMI

- \*ELECTROMAGNETIC INFLUENCES ON THE ORBITER AND OTHER EXPERIMENTS IS NOT PERMITTED.
  - ANALYSIS AND TEST DATA MUST DEMONSTRATE THAT THE HARDWARE DOES NOT RADIATE EMI BEYOND SPECIFIED, ACCEPTABLE LIMITS.

F. CREW INTERFACES

- \* SHARP EDGES
- \* LATCH DESIGN
  - PINCHED FINGERS
  - BUSTED KNUCKLES
  - HUMAN FACTORS





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III OPERATIONAL CONSTRAINTS

A. PRE-LAUNCH PREPARATIONS

\* EXPERIMENT PREPARATION FOR LOADING, INCLUDING GROUND STUDIES, FLIGHT  
BACK-UPS

- MINIMIZE LAST-MINUTE COMPLEXITY
- MINIMIZE LAST MINUTE WORKLOAD
- MINIMIZE NEED FOR COMPLEX LAB SUPPORT / HUMAN RESOURCES.

\* LATE ACCESS:      BEGINS AT LAUNCH MINUS 50 HOURS      (MAY CHANGE)  
                                 ENDS AT LAUNCH MINUS 13 HOURS

- MINIMIZE PERISHABLE / CONSUMABLE EXPERIMENT CONTENT
- MINIMIZE ENVIRONMENTAL CONTROLS NEEDED DURING LATE ACCESS  
LOADING

- CARRY-ON CONTAINERS

- MINIMIZE ENVIRONMENTAL CONTROLS NEEDED AFTER LOADING  
AND PRIOR TO POST-LAUNCH EXPERIMENT STARTUP



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III OPERATIONAL CONSTRAINTS (continued)

A. PRE-LAUNCH (continued)

- ORBITER / SPACELAB IN VERTICAL POSITION

- PERSONNEL PERFORMING LATE ACCESS LOADING ARE LOWERED INTO SPACELAB BY BOSUN'S CHAIR

- LATE ACCESS ITEMS SIZE LIMITED ACCORDINGLY
- MASS IS LIMITED
- COMPLEXITY OF LOADING OPERATION IS LIMITED
- MAN ON THE FLYING TRAPEZE.

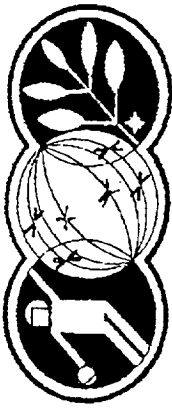
- POST EXPERIMENT LOADING, PRE-LAUNCH OPERATIONS (ON THE PAD TIME)

- VERY LIMITED UTILITIES AVAILABLE
- VERY LIMITED DATA EXCHANGE CAPABILITY
- EXPERIMENT SHOULD TAKE CARE OF ANY REQUIRED DATA ACQUISITION AND STORAGE.

- LIMITED ENVIRONMENTAL CONTROLS
- NO CREW INTERACTION WITH THE EXPERIMENT



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III OPERATIONAL CONSTRAINTS (continued)

A. PRE-LAUNCH (continued)

- LAUNCH DELAY
- EXPERIMENT MUST ACCOMMODATE MAXIMUM LAUNCH HOLD WITHOUT REQUIRING SERVICES - 24 MAXIMUM DELAY
- LAUNCH RESCHEDULE
- REPLACE/REFURBISH/REPLENISH CAPABILITY
- MUST BE READY TO FLY AGAIN WITHIN 72 HOURS

B. IN-FLIGHT

- SPACELAB / ORBITER CLOSED ENVIRONMENT
- LIMITED HEAT REMOVAL CAPABILITY
- LIMITED ELECTRICAL POWER CAPACITY
- ALLOW FOR CONTINGENCIES
- LIMITED 'GARBAGE' VOLUME AVAILABLE
- WHAT GOES UP MUST COME DOWN



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CONSTRAINTS ON EXPERIMENT HARDWARE

DATE:

10/31 - 11/4/88

III OPERATIONAL CONSTRAINTS (continued)

B. IN-FLIGHT (continued)

- NON GRAVITY ACCELERATIONS
  - ORBITER MANEUVERING/ATTITUDE CONTROL
    - RANDOM VECTORS
    - LIMITED SCIENCE CONTROL
      - MAKE NEEDS KNOWN EARLY ON
      - FACTOR INTO EXPERIMENT TIME-LINE
- CREW IMPOSED ACCELERATIONS
  - VIBRATION
  - ADJACENT DOOR/DRAWER CLOSURE
  - INADVERTANT CREW IMPACT WITH HARDWARE
- ORBITAL INCLINATION
  - MISSION SPECIFIC
  - MANIFEST IN ACCORDANCE WITH EXPERIMENT REQUIREMENTS



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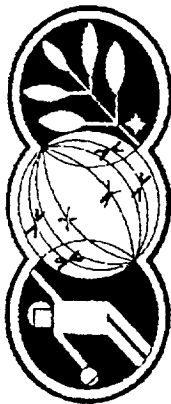
III OPERATIONAL CONSTRAINTS (continued)

B. IN-FLIGHT (continued)

- FIRST CREW ACCESS TO SPACELAB IS LAUNCH + 6 HOURS
- LIMITED CREW TIME (60% FIRST DAY, 75% THEREAFTER)
- USER FRIENDLY HARDWARE MAXIMIZES CREW PRODUCTIVITY
  - MINIMIZE ON-ORBIT COMPLEXITY
  - BDA
  - MINIMIZE THE NUMBER OF CREW OPERATIONS
  - MAXIMIZE EXPERIMENT SELF-SUFFICIENCY
    - OPERATION
      - DATA COLLECTION / CREW OBSERVATION
  - SEVERELY LIMITED ON-ORBIT REPAIR CAPABILITY
    - FEW TOOLS OR STOWAGE VOLUME FOR THEM
    - SEVERELY LIMITED TIME AVAILABLE FOR CREW/GROUND INTERACTIVE DIAGNOSIS
      - COMPLETE MALFUNCTION PROCEDURES ESSENTIAL
      - NO "BEAM ME UP SCOTTY" CAPABILITY AVAILABLE AT THIS TIME
  - THE BOTTOM LINE:
    - ON-ORBIT OPERATIONAL SIMPLICITY AT THE EXPENSE OF PRE-FLIGHT COMPLEXITY IS A GOOD TRADE-OFF
    - SIMPLICITY - SIMPLICITY - SIMPLICITY



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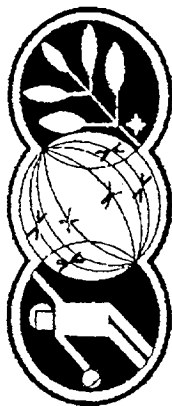
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III OPERATIONAL CONSTRAINTS (continued)

- C. POST FLIGHT
- RECOVERY TIMES
  - PRIME LANDING SITES
    - KSC
    - DRYDEN
      - 3 HOUR MINIMUM WAIT FOR ACCESS TO THE EXPERIMENTS
      - LIKELY TO INCREASE TO 24 HOURS PLUS
        - NO CREW INTERACTION
        - LIMITED UTILITIES
        - PROVIDE / SPECIFY NEEDED RECOVERY CONTROLS
          - ENVIRONMENTAL
          - ORIENTATION CONTROLS / SPECIAL HANDLING
          - MINIMIZE TIME-CRITICAL OPERATIONS
  - CONTINGENCY LANDING SITES
    - LENGTHY RECOVERY DELAYS
    - VERY LIMITED GROUND CREW / ORBITER SERVICING EQUIPMENT AVAILABLE
      - PROVIDE CONTINGENCY PLANS/PROCEDURES TO MITIGATE SCIENCE LOSS



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#### IV DOCUMENTATION REQUIREMENTS

##### - DOCUMENTATION MATURITY:

- PRELIMINARY DESIGN REVIEW (PDR)
  - HARDWARE PERFORMANCE REQUIREMENTS FROZEN /BASE-LINED
  - HARDWARE CONCEPTS ESTABLISHED
  - PRELIMINARY DRAWINGS COMPLETED AFTER INCORPORATION OF PDR COMMENTS
  - PERMISSION TO PROCEED AS BASELINED GRANTED
  - FINAL DESIGN AND DOCUMENTATION GENERATION STARTED
- CRITICAL DESIGN REVIEW (CDR)
  - BUILD-TO DRAWINGS REVIEWED AND APPROVED
  - DESIGNS REVIEWED AND ACCEPTED
  - DESIGN IS BASELINED
  - DRAWINGS FROZEN FOLLOWING INCORPORATION OF CDR COMMENTS
  - CHANGE CONTROL INVOKED
    - CHANGES FROM THIS POINT REQUIRE CHANGE CONTROL BOARD APPROVAL
- PERMISSION TO PROCEED WITH HARDWARE FABRICATION GRANTED
- PAYLOAD DOCUMENTATION UPDATED



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IV DOCUMENTATION REQUIREMENTS (continued)

- INTEGRATED PAYLOAD CRITICAL DESIGN REVIEW
  - MISSION PAYLOAD IS BASELINED
  - POST IPL/CDR CHANGES IMPACT:
    - GROUND INTEGRATION REQUIREMENTS DOCUMENT
    - INSTRUMENT INTERFACE AGREEMENT
    - OPERATIONS AND INTEGRATION AGREEMENT
    - INTEGRATED PAYLOAD REQUIREMENTS DOCUMENT
    - EXPERIMENT REQUIREMENTS SIMULATION DOCUMENTATION
    - STOWAGE LIST
    - MANY OTHER DOCUMENTS
    - TEST PROCEDURES
    - STOWAGE DRAWINGS
    - MASS PROPERTIES REPORTS
    - ENGINEERING DRAWINGS
    - MATERIALS USAGE LIST
- GENERAL RULE : THE LATER A CHANGE IS REQUESTED THE LESS CHANCE  
THE CHANGE HAS OF BEING APPROVED.





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### SUMMARY

THE MAJOR CONSTRAINTS CAN BE GROUPED AND CLASSIFIED AS FOLLOWS:

1. PHYSICAL CONSTRAINTS  
HOW BIG  
HOW HEAVY  
HOW MANY RESOURCES ARE NEEDED
2. SAFETY CONTSTRAINTS  
DOCUMENTATION AND TESTING MUST ASSURE THAT NO HARM WILL COME TO  
THE CREW OR ORBITER UNDER ANY FAILURE MODE.
3. OPERATIONAL CONSTRAINTS  
THE CREW HAS LIMITED TIME, AND RESOURCES AND IS OPERATING UNDER  
UNUSUAL CONDITIONS. (MICRO G)
4. DOCUMENTATION CONSTRAINTS  
FINALIZE REQUIREMENTS AS SOON AS POSSIBLE  
FINALIZE DOCUMENTATION AS SOON AS POSSIBLE

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THE BOTTOM LINE: KEEP HARDWARE SMALL, LIGHT, MINIMIZE COOLING AND POWER USE  
KEEP IT SIMPLE TO OPERATE AND MAKE IT AS SELF SUFFICIENT AS POSSIBLE



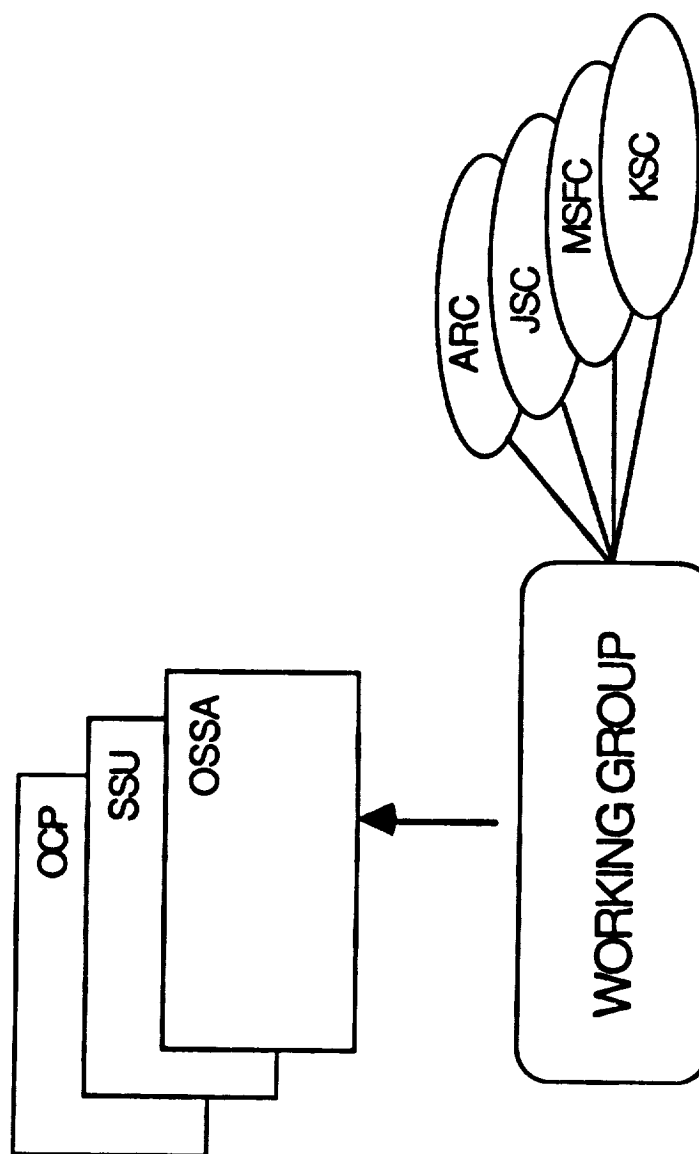
# **CELLS IN SPACE - II**

## **NOVEMBER 3, 1988**

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**L.A. MILOV  
CHAIRMAN, COMMERCIAL LIFE SCIENCE WORKING GROUP**

# WORKING GROUP COMMERCIAL LIFE SCIENCE ADVOCACY FLOW DIAGRAM



**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**Workshops**

**Background And Status**

- Summer 1988 Workshop in California
- Fall 1988 Sub-Panel at Denver Space Station Workshop
- Winter 1988 Workshop at Kennedy Space Center

**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS  
OVERVIEW**

- **Developing and Implementing A NASA Research Announcement in Commercial Life Sciences**
- **Getting More Mileage Out of Small Business Innovation Research Awards In Life Sciences**
- **Providing a Focus for Space Station Mission Requirements in Commercial Life Sciences**
- **Continuing to Support Commercial Life Science Workshops**

# COMMERCIAL LIFE SCIENCE WORKING GROUP ADVOCACY FOCAL POINTS

## NASA Research Announcement in Commercial Life Sciences

### Proposed Program Goal and Objectives

#### GOAL

Based on a partnership between OCP and the Life Sciences Division, use the NRA as a mechanism to stimulate commercial investment and involvement in ground and space-based life science initiatives which support NASA's long-term life sciences program goals.

#### OBJECTIVES

- . Stimulate commercially-sponsored basic research in commercial life sciences
- . Increase the profile of NASA's life science program with U.S. industry, and stimulate the number of opportunities for industry to exploit unique NASA expertise and facilities in life sciences
- . Build upon the partnerships which have been established between NASA, industry and universities in life sciences (e.g Centers for the Commercial Development of Space)
- . Provide the life sciences program at NASA with greater feedback on commercial user requirements

**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**NASA Research Announcement in Commercial Life Sciences**

**Background**

- **Jointly Funded (Code C/Code EE) NASA Research Announcement for the Remote Sensing Applications/Commercialization Program**
- **OCP New Initiatives Task Team Life Sciences Sub-Panel Recommendation in Support of NRA in Commercial Life Sciences**
- **Industry Workshops in Life Sciences Sponsored by the Commercial Life Sciences Working Group**



**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**NASA Research Announcement in Commercial Life Sciences**

**Potential Research Areas**

- **Controlled Ecological Life Support Systems**
- **Biospherics**
- **Gravitational Biology**
- **Bioprocessing**
- **Biomedical Research**

**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**Small Business Innovation Research**

**Background**

- **Inclusion of Commercial Life Sciences Sub-Topic in SBIR Solicitation**
- **Participation of Life Sciences CCDS' in SBIR Proposals**
- **OCP New Initiatives Task Team Recommendations to Strengthen SBIR Support of Commercial Life Sciences Initiatives**

**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**Small Business Innovation Research**

**Objectives**

- **Implement OCP Task Team Life Sciences Sub-Panel Recommendations on Commercial Life Sciences:**
  - - **Incentivize SBIR Awardee Collaboration with Industry to Facilitate Transition to Phase III Funding;**
- **Increasing the Number of SBIR Awardees in Commercial Life Sciences**
- **Provide Dedicated SBIR Selection in Commercial Life Sciences At Each Field Center**

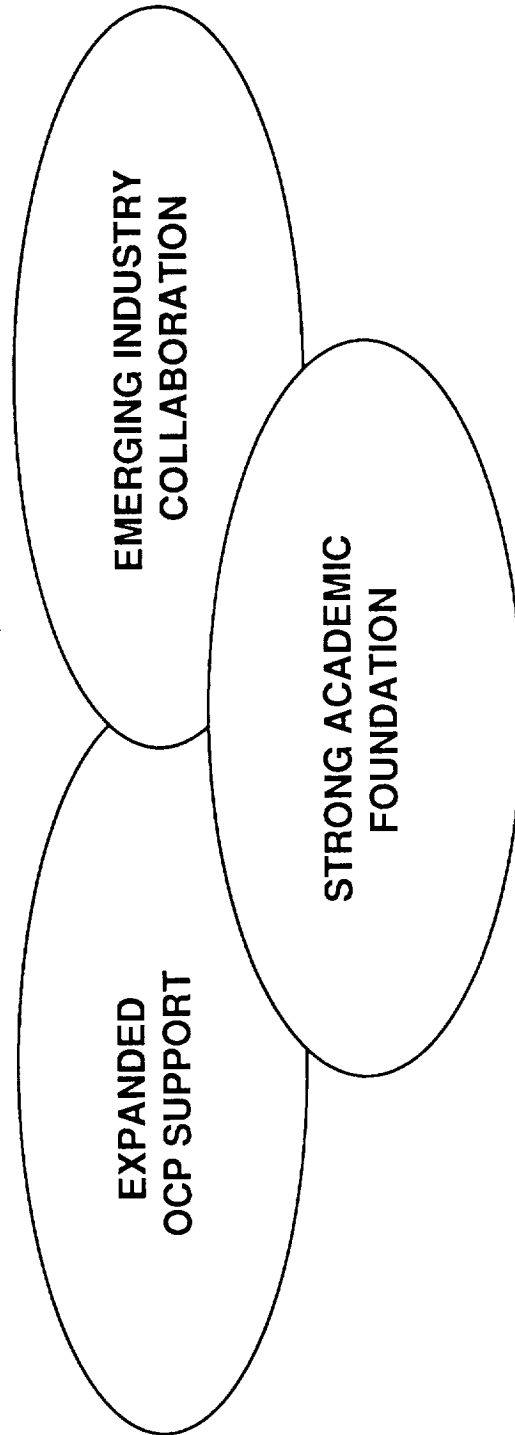
**COMMERCIAL LIFE SCIENCE WORKING GROUP  
ADVOCACY FOCAL POINTS**

**Serving As A Focus for Mission Requirements**

**Background And Status**

- **Commercial Life Sciences Working Group Originally Chartered as a Mechanisms for Generating Space Station Mission Requirements**
- **CLSWG Has Provided OCP (CD/Oran) With "Placeholder" Commercial Life Sciences Missions**
- **CLSWG Working With MSFC/Fountain to Input Commercial Life Science Requirements Into Space Station Payload Manifest**

**HERE WE GO ...**



## **ACCOMPLISHMENTS**

- ORGANIZED COMMERCIAL LIFE SCIENCES WORKING GROUP
- FACILITATED SELECTION OF TWO CCDS IN LIFE SCIENCES
- CREATED COMMERCIAL LIFE SCIENCES SBIR SUB TOPIC
- IDENTIFIED COMMERCIAL LIFE SCIENCE INITIATIVES FOR OCP TASK TEAM
- FIRST COMMERCIAL LIFE SCIENCES SUB PANEL
  - 1988 SPACE STATION FREEDOM WORKSHOP

## **PURPOSE OF SUB-PANEL**

- DESCRIBE NASA'S LIFE SCIENCE PROGRAM AND POTENTIAL AREAS FOR COLLABORATION.
- DISCUSS MECHANISMS AVAILABLE FOR INDUSTRIAL COLLABORATION
- STIMULATE DIALOGUE ON HOW NASA CAN RESPOND TO INDUSTRY'S RESEARCH AGENDA IN LIFE SCIENCES

**AMES SUPPORT FOR  
COMMERCIAL LIFE SCIENCE RESEARCH**

- ACCESS TO NASA INVESTIGATORS AND FACILITIES
  - SCIENTISTS AND ENGINEERS PERFORMANCE EVALUATIONS
  - AGREEMENT MECHANISMS
- SMALL BUSINESS INNOVATION RESEARCH PROGRAM
  - SUB TOPIC ESTABLISHED
  - 2 PHASE I AWARDS IN FY 88
- BIOSERVE, UNIVERSITY OF COLORADO BOULDER
  - CONTROLLED GRAVITY TECHNOLOGY, 1.8 METER CENTRIFUGE
  - MEMBER COMMERCIAL LIFE SCIENCE WORKING GROUP
- CENTER FOR CELL RESEARCH, PENN STATE
  - ANIMAL ENCLOSURE MODULE
  - MEMBER COMMERCIAL LIFE SCIENCE WORKING GROUP
- UNIVERSITY OF WISCONSIN, MADISON, WISCONSIN





OFFICE OF  
COMMERCIAL  
PROGRAMS

## PRELIMINARY LISTING OF CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE CORPORATE AFFILIATES

119 CORPORATE

AMOCO CHEMICALS CORPORATION	BIOCRYS	EDISON POLYMER INNOVATION
PPG INDUSTRIES, INC.	ALCOA	DOVAL COMPOSITES, INC.
ROCKWELL INTERNATIONAL	ARMCO, INC.	LeMONT SCIENTIFIC, COMPANY
E.I. DuPONT	ALLIED SIGNAL	COULTER
II-VI, INC.	CABOT, CORP.	SUPELCO
HERCULES	ENGLEHARD CORP.	SCIENTIFIC SYSTEMS, INC.
BOEING AEROSPACE COMPANY	GENERAL ELECTRIC	ZETACHRON
FRONTIER RESEARCH	GENERAL MOTORS	MONOCLONAL PRODUCTION
DEERE AND COMPANY	GTE	DIGENE
IBM ALMADEN	LOCKHEED	SCIENTIFIC ENTERPRISES
MARTIN MARIETTA AEROSPACE	GRUMMAN CORP.	ELECTROPORE, INC.
McDONNELL DOUGLAS CORP.	TRANS-TEMP	BEND RESEARCH
TELEDYNE BROWN ENGINEERING	WESTINGHOUSE	GELMAN SCIENCES
WYLE LABORATORIES	DANTEC ELECTRONICS	MICKLEY & ASSOCIATES
MASSCOMP	QUANTUM TECHNOLOGIES	PRECISION SCIENTIFIC
INTERNATIONAL PAPER	BARNES ENGINEERING	BALL AEROSPACE
SOIL TECH, INC.	SPACEHAB	ALZA
EXXON	SPECTRON LABORATORIES	MAXWELL LABORATORIES
MURPHY OIL	ELECTRO-OPTIK	ROCKETDYNE
FREEMPORT McMORAN	PERKIN ELMER	SATURN CORP.
APPLE COMPUTERS	INSTRUMENTS S.A., INC.	SYMBOLICS, INC.
HARDING LAWSON & ASSOCIATES	BEAVER DAM EMERGING GROWTH	TECHNION, INC.
PALEN FARMS, INC.	GAMMEX, INC.	PEPCO
GEOSTAR, INC.	DELCO	GULF STATE UTILITIES
VERSATEC	JOHNSON CONTROLS, INC.	ENTECH, INC.
PIONEER SEED COMPANY	MADISON KIPP, INC.	ARTHUR D. LITTLE
TENNECO OIL COMPANY	PHYTO FARMS OF AMERICA	FORD AEROSPACE
BRITISH PETROLEUM	PIERSON PRODUCTS, INC.	SOLAR ENERGY RESEARCH INSTITUTE
FIRST NATIONAL BANK OF TONKAWA	SILICON SENSORS	ELECTRIC POWER RESEARCH INSTITUTE
BANK OF WELLINGTON	SNAP-ON-TOOLS	COMSAT CORP.
ASTRONAUTICS CORP. OF AMERICA	SUNDSTRAND CORP.	EAGLE Picher, INC.
AT&T	SEVRAIN TECH, INC.	E-SYSTEMS, INC.
SCHERING CORP.	AMERICAN ELECTRIC POWER COMPANY	GENERAL DYNAMICS
PROCTOR & GAMBLE	TRIMBLE NAVIGATION	ELECTROCHEM, INC.
DOW CHEMICALS	GAS RESEARCH INSTITUTE	FAIRCHILD
SMITH, KLINE & BECKMAN	SYNERCOM, INC.	KMS FUSION
ELI LILLY	DEC	GEOSPECTRA, INC.
MERCK, SHARPE & DOME	3M	DUPERON, INC.
UPJOHN	GOODYEAR	INVITRON
EASTMAN KODAK	TRW	

## **CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE UNIVERSITY AFFILIATES**

32 = UNIVERSITIES

AKRON UNIVERSITY  
CASE WESTERN RESERVE UNIVERSITY  
CLARKSON UNIVERSITY  
CLEVELAND UNIVERSITY  
OHIO STATE UNIVERSITY  
WASHINGTON STATE UNIVERSITY  
WORCESTER POLYTECHNIC  
UNIVERSITY OF MAINE  
MURRAY STATE UNIVERSITY  
FLORIDA STATE UNIVERSITY  
MONTANA STATE UNIVERSITY  
UNIVERSITY OF SOUTHERN MISSISSIPPI  
PURDUE UNIVERSITY  
UNIVERSITY OF ALABAMA - HUNTSVILLE  
UNIVERSITY OF ALABAMA - TUSCALOOSA  
UNIVERSITY OF FLORIDA - GAINESVILLE

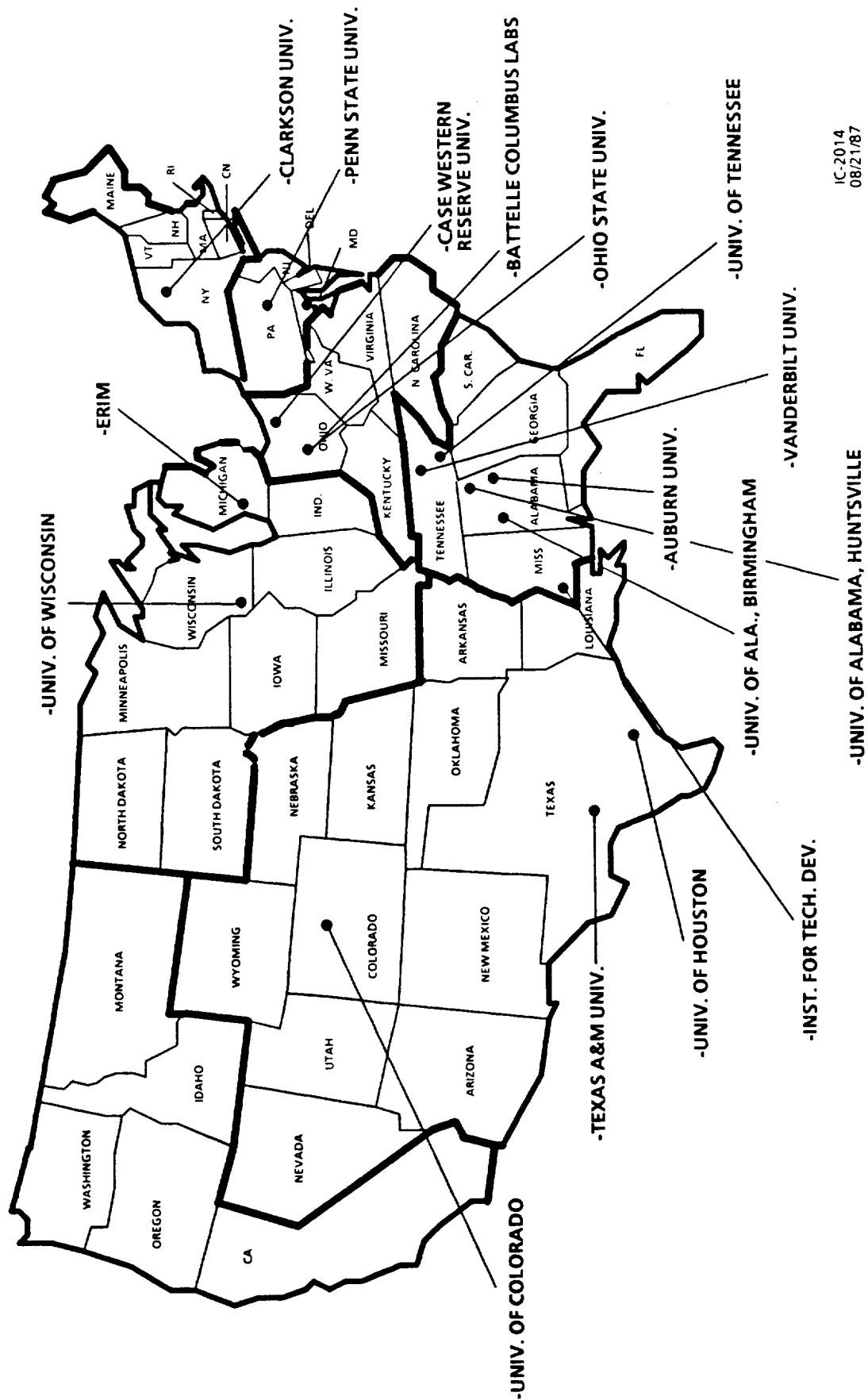
ALABAMA A&M UNIVERSITY  
UNIVERSITY OF FLORIDA  
RENSSELAER POLYTECHNIC INSTITUTE  
UNIVERSITY OF ILLINOIS - URBANA  
UNIVERSITY OF WISCONSIN - MADISON  
KANSAS STATE UNIVERSITY  
UNIVERSITY OF UTAH  
UNIVERSITY OF COLORADO - DENVER  
FLORIDA A&M UNIVERSITY  
UNIVERSITY OF BUFFALO  
UNIVERSITY OF SOUTH CAROLINA  
TENNESSEE STATE UNIVERSITY  
AUBURN UNIVERSITY  
PRAIRIE VIEW A&M UNIVERSITY  
LAMAR UNIVERSITY  
UNIVERSITY OF TEXAS AT ARLINGTON

## **CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE CURRENT STATUS**

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- 32 UNIVERSITY PARTICIPANTS
- 119 INDUSTRIAL BUSINESS PARTICIPANTS
- IDENTIFIED 129 PRODUCTS/PRODUCT CATEGORIES
- 615 DROP TUBE/TOWER EXPERIMENTS
- 21 KC-135 FLIGHT EXPERIMENTS
- 1 SERIES OF LEAR JET FLIGHTS
- 4 STS FLIGHTS
- 5 EXPERIMENTS PREPARED FOR FIRST SOUNDING ROCKET FLIGHT
- SMALL BUSINESS PARTICIPATION BEING DEVELOPED FOR SMALL BUSINESS INNOVATION RESEARCH AWARDS

# CENTERS FOR COMMERCIAL DEVELOPMENT OF SPACE NATIONWIDE



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# **CENTERS FOR THE COMMERCIAL DEVELOPMENT OF SPACE OBJECTIVES AND CRITERIA**

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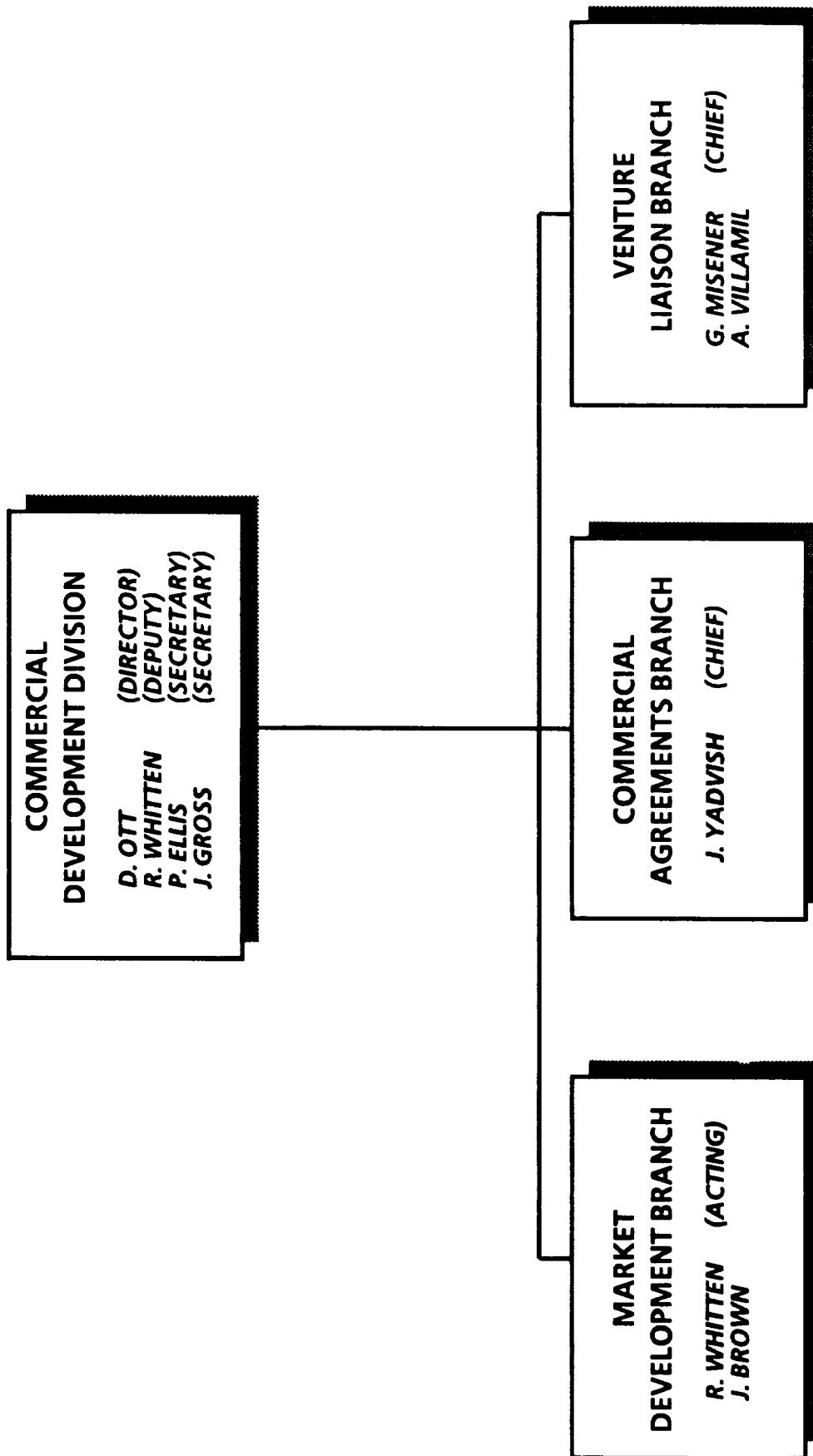
## **OBJECTIVE**

- PROVIDE THE PATHWAY FOR U.S. INDUSTRY TO DEVELOP LEADERSHIP IN THE  
COMMERCIAL USE OF SPACE
  - DEVELOPING PROGRAMS THAT FOSTER NEW TECHNOLOGY DEVELOPMENT
  - DEVELOPING PROGRAMS THAT LEAD TO NEW COMMERCIAL PRODUCTS

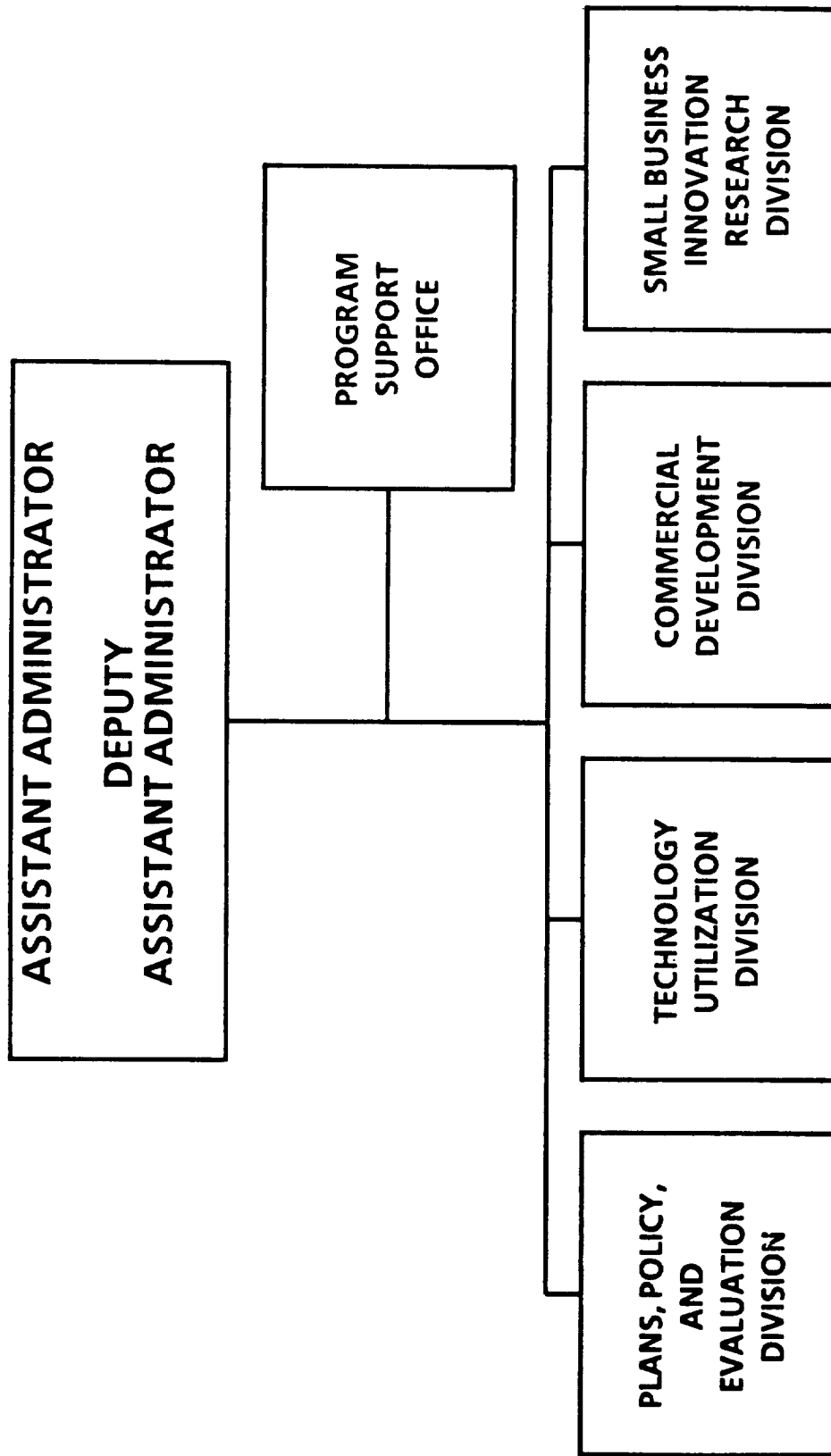
## **GENERAL CRITERIA**

- NEW AND UNIQUE TECHNOLOGY DEVELOPMENT AND SYSTEMS LEADING TO  
COMMERCIAL USE OF THE SPACE ENVIRONMENT
- HIGHLY SPECIALIZED UNIVERSITY BASED CENTERS TO HELP U.S. INDUSTRY FOCUS ON  
TECHNOLOGY DEVELOPMENTS THAT ARE COMMERCIALY-ORIENTED
- SYSTEMATIC EVOLUTION OF CENTERS TO BECOME HIGHLY INDEPENDENT OF NASA  
THROUGH THEIR DEVELOPMENT OF INDUSTRIAL COMMITMENT

# OFFICE OF COMMERCIAL PROGRAMS



# OFFICE OF COMMERCIAL PROGRAMS ORGANIZATION



# EXECUTIVE AND LEGISLATIVE BRANCH PRONOUNCEMENTS IN SUPPORT OF COMMERCIAL SPACE

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*"We will soon implement a number of executive initiatives, develop proposals to ease regulatory constraints, and with NASA's help, promote private sector investment in space."*

State of the Union Address, 1984

*"In the zero gravity of space, we could manufacture in 30 days life saving medicines it would take 30 years to make on Earth. We can make crystals of exceptional purity to produce super computers, creating jobs, technologies and medical breakthroughs beyond anything we ever dreamed possible."*

State of the Union Address, 1985

*"The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration seek and encourage to the maximum extent possible, the fullest commercial use of space."*

Public Law 98-361, 1984

**MAINTAINING AND ENHANCING  
U.S. LEADERSHIP IN  
COMMERCIAL SPACE ACTIVITIES**



## CONCLUSIONS/CLOSING REMARKS

Robert S. Bandurski and Paul Todd

This conference marks a watershed between the period when space was being tested for safety and the new period in which space is regarded as an important adjunct to our studies of biological, physical, and chemical phenomena. It was implicit in the numerous presentations and discussions that there will be increasingly frequent opportunities for experimentation in space, that generic hardware will facilitate the performance of space experiments, and that there will be commercial utility to space. Most importantly, there was a melding of physical and biological knowledge and an emphasis on how the weak forces of gravity are able to affect organisms composed of covalent and non-covalently bonded molecules.

It was correctly observed during the conference that it is the life forms that have developed, evolved, and grown on earth that constitute the 1-g experiment. The micro-g, and fractional-g controls attainable in space have, in general, rarely been done. We are now ready to study the micro-g controls and, for the first time, to understand the effects of 1-g.

This conference has convinced us that complex biological systems will greatly contribute to our knowledge of the physics of gravity.



## CONFERENCE DEDICATIONS

### Professor George Nace

(Provided by Kenneth Souza)

George Nace was born in 1920 in Cogsville, Pennsylvania. His parents were missionaries in Japan where, in his early childhood, he developed fluency in Japanese. During the second World War he was actively engaged for 2-3 years as an interpreter with the occupation forces where his fluency in Japanese was valuable. After his early years in Japan he came back to the United States, where he attended Reed College in Oregon and earned a degree in Biology. He then went to UCLA and obtained his masters and doctoral degrees in Zoology. Following a few years doing post-doctoral work, he joined the staff at the University of Michigan in 1957, where he remained until 1984 when he retired as Professor Emeritus. He died in 1987.

It was during his tenure at University of Michigan, that I first became acquainted with him and his involvement in the frog rearing and culturing activities. He was a great proponent of ecological studies of amphibia and an expert in their nurturing and rearing in the laboratory. By carefully controlling the environment in which the amphibia were reared, Professor Nace could guarantee the quality of specimens for the investigator. When Rana pipiens became difficult to obtain because of over-collection during the 1960's and 70's, he became a supplier in every sense of the word. He founded his own company and had facilities where he developed a feeding technique which enabled him to raise Rana pipiens through metamorphosis to the adult stage. A 1985 issue of *Science* magazine featured Professor Nace and described his forte: the culture and rearing of a wide variety of "designer" amphibia or genetically-marked strains.

In 1978 Professor Nace joined with John Tremor, Muriel Ross and me to develop the Frog Embryology Experiment now scheduled to fly on Spacelab J. While he remained a member of the Frog Embryology experiment his primary focus was on teaching, particularly in teaching students to convey the message that amphibia could be raised in the laboratory setting. Some of his students returned to Korea and Japan where, as a consequence, he came to be a recognized and respected expert in amphibian biology. Over the past two decades Professor Nace served on a variety of NASA advisory committees and working groups. He was one of the first space biologists to recognize the need to include physicists in the analysis of microgravity experiments. It was during collaboration with a few physicists at the University of Michigan that Professor Nace developed what he called the torsional model of gravitational effects on the cell. The subject and focus of this event is a tribute to some of the insights and ideas of Professor Nace. I am pleased to dedicate this conference to him.

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## **Professor Per F. Scholander**

**(Provided by Robert S. Bandurski)**

The Cells in Space Conference deals with the most exciting voyage on which humans have yet embarked -- the voyage into space. Thus, it is singularly appropriate that this conference be dedicated to Professor Per F. (Pete) Scholander -- a pathfinder of the first order. He knew that opportunities to understand life processes lie at the fringes of our environment--where living creatures face extremes of cold and heat, of wet and dry, of salty and salt free. He realized that it was at these extremes that life would most vividly reveal its secrets. Of all scientists he would have shared our excitement at the prospects of this journey into space.

Scholander was Professor Emeritus of Physiology and the first Director of Scripps's Physiological Research Laboratory. He was born in Orebo, Sweden on November 29, 1905, and moved to Norway at an early age. He received his Doctorate in Medicine from the University of Oslo, Norway, in 1932 and the Doctorum Honoris Causa from Uppsala in 1977. He was elected to the National Academy of Sciences and the American Philosophical Society. He died on June 13, 1980, in La Jolla, a suburb of San Diego, California, at the age of 74.

Scholander had many research accomplishments usually characterized by the use of extraordinarily simple equipment, often built by himself, and capable of use in the extreme environments of the field. These included the Wick Technique for measurement of fluid pressures in animals and the Pressure Bomb for measuring solute osmotic pressures in plants. He was fascinated by the problem of getting water to the top of tall trees and, in this connection, used a rifle to shoot down branches from 100-meter-tall trees so their osmotic pressures might be measured. He investigated blood circulation and respiratory problems in diving animals, particularly the physiological mechanisms which act to prevent oxygen deficiency in brain tissue. He studied bradycardia, the cutting off of peripheral circulation, which developed in mammals upon submersion in water, or in fish upon removal from water. He studied climatic adaptations in arctic and tropical animals and the dynamics of negative tissue-fluid pressures in animals. He advanced the idea that an anti-free substance is present in fish living in polar waters and was among the first to analyze the composition of gas bubbles in glacial ice to determine atmospheric conditions in ancient times.

Professor Scholander was responsible for obtaining funds from the National Science Foundation for building and operating the Alpha Helix--the world's first floating physiological biochemistry laboratory. The Alpha Helix, in addition to well-equipped laboratories, had an ice breaking prow and the stern of a Norwegian Whaler to carry scientists to the extremes of the world's climatic conditions.

How fitting that we should also dedicate this conference to Professor Scholander. We hope that memories of his vision will accompany us into the environs of space.

## ATTACHMENTS

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## ATTACHMENT A

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## **ATTACHMENT B**

### **CELL RESEARCH EXPERIMENTS (FLOWN/PLANNED)**

1. Plant/Animal Cell Cultures
2. Oocyte/Embryo Development
3. Microorganisms

The following tables provide a recent collection of space cell research experiments that have flown, or are planned. The experiments were obtained from a selected literature search and are divided into three groups: Plant/Animal Cell Cultures, Oocyte/Embryo Development, and Microorganisms.

Information provided in the tables includes: the name of the experiment, the mission on which it was flown/planned and the year, a brief description of the flight hardware, and a reference source (see Attachment D). In addition, the table for Plants/Animal Cell Cultures provides the organism used for the culture. The experiments are arranged in ascending order according to the date of the mission and each has been assigned a number for references purposes.

Several experiments refer the reader to the Cell Research Flight Hardware descriptions in Attachment C (obtained from references in Attachment D).

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# 1. Plant/Animal Cell Cultures

#	EXPERIMENT	ORGANISM	FLOWN/PLANNED	HARDWARE	REF.
A1	The Effects of Space Flight on Living Human cells - Chicken embryo tissue		Discoverer XVIII ('60)	Glass ampules, salt solution, 10% horse serum, refrig. units, neutron film pack, chem. dosimeters, gold foil, glass needle sets, 552 film strips, polyethylene foam (packing), alanine pcts, 1 step plate & film, nuclear track plates	(1) p. 121
A2	Exposure to Spaceflight	Hela Cultures	Sputnik 4 ('60)		(5) pp. 36-37
A3	Exposure to Spaceflight	Hela Cultures	Sputnik 6 ('61)		(5) pp. 36-37
A4	Exposure to Spaceflight	Hela Cultures	Sputnik 7 ('61)		(5) pp. 36-37
A5	Exposure to Spaceflight	Hela Cultures	Vostok 1 ('61)		(5) pp. 36-37
A6	Exposure to Spaceflight	Hela culture	Vostok 2 ('61)		(5) pp. 36-37
A7	Exposure to Spaceflight	Hela culture	Voshkod-2 ('65)		(5) pp. 36-37
A8	Radiation and Zero-G Effects on Human Leukocytes and Neurospora crassa	Human, Microorganism	Gemini 3, 11 ('65, '66)	32P source, alum. blood-sample holder, dosimeter rods	(1) p. 155
A9	Radiobiological Studies of Tradescantia Plants Orbited	Plant Tradescantia	Biosat II ('67)	Expt pckgs of polypropylene plastic to hold 32 plants with nutrient solution thermistor, dosimeters	(1) p. 152
A10	Exposure to Spaceflight	Hela Cultures	Zond5 ('68)		(5) pp. 36-37
A11	Cell Growth in "Bioterm"	Cells from Syrian hamster (strain VNK-21)	Kosmos 368 ('70)	Bioterm apparatus temp. control	(5) pp. 36-37
A12	Effects of ZeroG on living cells	Human embryonic lung cells (WI-38)	Skylab 3 ('73)	Woodlawn Wanderer 9. See Hardware Section 1.	(2) p. 221
A13	Cytoplasmic Streaming	Water weed (Elodea)	Skylab 3, 4 ('73)	Vials, microscope slides, cover slips, tweezers, microscope, camera adapter, 16mm motion picture camera	(1) p. 149

1. Plant/Animal Cell Cultures (Continued)

#	EXPERIMENT	ORGANISM	FLOWN/PLANNED	HARDWARE	REF.
A14	Electrophoresis Experiment MA014	rat bone marrow, spleen, lymph node cells with addition of human erythrocytes as mar- kers and a mixture of human and rabbit erythrocytes	Apollo-Soyuz Test Project ('75)	Separation chamber consisting of 2 cooling plates. Electrodes	(1) p. 111
A15	Electrophoresis Tech. MA011	Human, rabbit, & horse erythrocytes	Apollo-Soyuz Test Project ('75)	electrophoresis unit, a a cryogenic freezer, 8 expt columns, 8 sample insertion slides	(1) p.97
A16	Carrot Tumor Growth Expt.	Crown gall tumors developed on carrot disks	Kosmos 782 ('75)	Specially machined acrylic canisters, consisting of a stack of 3 closely fitted dishes. 2 machined anodized aluminum caps; filter pads with 12 air holes (pics in Final rept)	(6) p. 33
A17	Carrot Tissue Culture	Cultured carrot toti- potent cells	Kosmos 782 ('75)	Specially constructed canisters, plastic petri dishes; 2 anodized alum- inum alloy end -caps 12 air holes; 4 standoffs (picture in Final report)	(6) p. 71
A18	Cytological Studies of Mammalian Cell Cultures	Chinese hamster & mouse cells	Cosmos 1129 ('79)		(7) p. 9
A19	Studies of Carrot Crown Gall Tumor Growth		Cosmos 1129 ('79)		(8) p. 57
A20	Studies of Carrot Tissue Culture Morphogenesis		Cosmos 1129 ('79)	Basal medium of salts, sucrose, vitamins NAA	(8) p. 57 Pics of hardware, p 80
A21	Efficiency of Separation of cells in weightlessness	Rat pituitary cells	STS-8 ('83)		(3) p. 145
A22	Effects of low gravity on Mammalian Cell Polarization at the Ultrastruct. level	mammal plasma cells	Spacelab D-1 ('85)	Blood kit, Cell Culture Flasks, Syringes, Medium, Type 1 experiment containers. See Hardware Section 2.1, 2.2, 2.3, 2.4, & 3.	(4) p. 105

1. Plant/Animal Cell Cultures (Concluded)

#	EXPERIMENT	ORGANISM	FLOWN/PLANNED	HARDWARE	REF.
A23	Separation of Animal Cells and Cellular Organelles by Means of Freeflow Electrophoresis	Cultured mammalian cells and their hybrid derivatives	Spacelab J ('91)	Free Flow Electrophoresis unit (FFEU) See Hardware section 13	(14) p. 26
A24	Rearrangement of Intermediate Filaments in Mammalian Cells in Culture	Several types of mammalian cells and tissues	Spacelab J ('91)	Thermoelectric Incubator (TEI) See Hardware section 14	(14) p. 30



## 2. Oocyte/Embryo Development

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
	Embryogenesis - Ascaris eggs	Sputnik 6 ('61)		(5) p. 31
B2	Sea Urchin Egg Fertilization and Development	Gemini 3 ('65)	Cylinder of 8 specimen chambers, each divided into 3 compartments separating sperm, ova and fixative solution	(1) p. 139
B3	Embryology development studies - 20 Rana eggs	Gemini 8 ('66) Gemini 12 ('66)	4 specially developed acrylic chambers, temp held at 4 C then raised to 21 C at orbit. Eggs then injected with glutaraldehyde fixative at various stages.	(9) p. 193 (10) p. 62
B4	Effect of Weightlessness on the Dividing Eggs - (B. frog) - 120 Rana eggs	Biosat. I ('66) Biosat. II ('67)	16 acrylic modules divided into 2 chambers, a 10 ml egg chamber, and a 4 ml-fixative chamber, a coolant line around the pkg to maintain it at 42.5 oF, thermistors	(1) p. 137
B5	Amphib. development - differentiation and function of the gravity sensing system in early embryos exposed to microgravity.	Soyuz-9 ('70) Soyuz 17 ('75) Soyuz 26 ('77) Soyuz 36 ('80) Soyuz 39 ('81) Soyuz 40 ('81)	Placed eggs from Rana temporaria and Xenopus laevis in containers. At various stages of development, glutaraldehyde was injected manually.	(5) p. 27 (10) p. 62
B6	BIOSTACK I, II To study biological effects of individual heavy nuclei with high energy loss (HZE) - Brine Shrimp eggs	Apollo 16, 17 ('72)	Hermetically sealed aluminum container, containing series of select biologic mat'l each sandwiched b/t several types of dosimeters and thermistors	(1) p. 128
B7	BIOSTACK II - Grasshopper eggs	Apollo 17 ('72)		(1) p. 129
B8	BIOSTACK II - Flour beetle eggs	Apollo 17 ('72)		(1) p. 130
B9	Development of Fundulus heteroclitus - 50 fert. eggs	SkyLab 3 ('73)	No special equipment (not intended to be an experiment)	(9) p. 193

## 2. Oocyte/Embryo Development (Continued)

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
B10	Fundulus dev. - 500 embryos	Apollo-Soyuz ('75)		(9) p. 194
B11	5 development stages of Fundulus studies (500 embryos)	Kosmos 782 ('75)	Machined aluminum, 2 chamber, cuboid case with 5 polyethylene bags (Picture in Final rept)	(6) p. 179
B12	BIOSTACK III To study the influence of HZE particles on development, morphogenesis, and histology - Brine S., flour b. & grass-H. eggs	Apollo-Soyuz Test Project ('75)	PVA, 2 cylindrical aluminum containers, K2 nuclear emulsion plates	(1) p. 131
B13	Killifish Hatching and Orientation	Apollo-Soyuz Test Project ('75)	Transport control pkg, experimental pkg, rotating striped drum, photog. equipment	(1) p. 132
B14	Study of Embryogenesis in Jap. Quail - 60 Coturnix eggs	Cosmos 1129 ('79)	Incubator	(9) p. 196; (7) p. 324
B15	Embryogenesis & Organogenesis in spaceflight - Stick insect Carausius	Spacelab D-1 ('85)		(4) p. 107
B16	Fertilization & Development in Spaceflight - M&F gametes African Clawed frog	Spacelab D-1 ('85)	Special containers with 6 compartments were fabricated for individual storage of eggs, sperm glutaraldehyde fixative, Ringers solution, distilled water, and an anti-sperm sera to label the spot of sperm penetration. Temp. maintained in chambers at 11 C until orbit. 1 to 2 hours after reaching orbit, chambers placed in incubator at 22 C. A microprocessor on each container then activated plungers in each chamber mixing sperm and eggs and subsequently flooded them with dilute Ringers solution. Fixation of all specimens occurred about 8 to 9 hours after fertilization (at gas-trula stage).	(10) p. 64

## 2. Oocyte/Embryo Development (Concluded)

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
B17	Embryonic Development of the Vertebrate Gravity Receptors - Clawed frog eggs	Spacelab D-1 ('85)	Fertilized eggs stored at 10 C in incubator located in a Space Shuttle middeck locker. 7 hours after launch, the developmental rate was accelerated by raising temp. to 20 C with in incubator in spacelab.	(10) p. 63
	<b>FUTURE EXPERIMENT:</b>			
B18	Fertilization and development in Microgravity	Spacelab-J ('91)	Designed to fly 4 adult females. Spacelab crew to induce ovulation and subsequent fertilization during the flight. Damp foam-lined box through which 100 cc/min of air will be circulated. Sperm suspension will also be prepared. Adult Frog Container (AFC) loaded into a special incubator, The Frog Environmental Unit (see fig.) located in the spacelab. AFC will be transferred to the General Purpose Work Station ( a glovebox containing chemical and biological materials - see fig.). In the GPWS, the frogs will be injected with chorionic gonadotropin to induce ovulation. Chambers filled with dilute Ringers solutions will hold eggs covered with sperm suspension. Incubation temp. will be 21 C. See Souza article for details.	(10) p. 65 pics on pp. 66,67

### 3. Microorganisms

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
C1	Radiobiology Expts - II Kleistridia Spore labilization: A Biological System to quantitate radiation	Discoverer XVII, XVIII ('60)	Caramelized glucose, glass ampules refrig. units for the ground, thermistors track plates, chem. dosimeters, needle sets	(1) p. 157
C2	Correlate traversal of primary cosmic rays with an increase in mutation in a population of cells lying along the track path - Neurospora crassa	Discoverer XVIII ('60)	Biological track plate, millipore filters, photog. emulsion on a 2"x2" sheet of glass, neutron sensitive film, Ansco 552 film, antimony foil, alanine and albumin	(1) p. 159
C3	Experiments with Photo- Synthetic Organisms - Algae	Discoverer XVII ('60)	Glass vials, chem. dosimeters, modi- fied Kratz's medium (D-17), Evelyn photoelectric colorimeter, alanine, albumin, silver-activated phosphate glass rods, Ansco 522 Film, neutron sensitive film, antimony foil, nuclear track plates	(1) p. 166
C4	Genetic Experiments on NERV - Neurospora crassa	NERV 1 ('61)	Experiment capsules	(1) p. 158
C5	Survival - Actinomycetes	Sputnik 6 ('61)		(5) p. 35
C6	Survival - Actinomycetes	Sputnik 7 ('61)		(5) p. 35
C7	Survival - Yeast	Vostok 2 ('61)		(5) p. 31
C8	Survival - Yeast	Voskhod 1 ('64)		(5) p. 31
C9	Mutational and Physiological Responses of Habrobracon - Parasitic wasp, brine shrimp cysts, Saccharomyces cerevisiae	Biosat II ('67)	Habrobracon flight containers, 85Sr source, LIF powder, glass rod dosimeters	(1) p. 135
C10	Mutagenic effectiveness of Known Doses of Radiation in Combination with Zero-G on Neurospora crassa	Biosat II ('67)	Millipore filters, LIF disk dosimeter, porous retaining rings, module of sample holders, 85Sr source, thermistor	(1) p. 160

### 3. Microorganisms (Continued)

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
C11	Effects of Weightlessness on the Nutrition and Growth of <i>Pelomyxa carolinensis</i> Amoeba	Biosat II ('67)	Expt pkg with 24 chambers each divided into 3 5-ml compartments containing eather amoeba, paramedium or fixitive. The chambers were mounted on magnesium plates. 4 of the chambers contained thermistors.	(1) p. 95
C12	Nuclear and Cellular Division in <i>Pelomyxa carolinensis</i> during Weightlessness (Amoeba)	Biosat II ('67)	same as (7)	(1) p. 103
C13	Radiation Exposures During Flight - Variety Animal & Plant microorganisms	Biosat II ('67)	Capsule, experiment pkgs, nuclear emulsion pkg, back-scatter shield, heat shield, source holder, 85Sr source, LiF powder dosimeters, CaF2 dosimeters	(1) p. 119
C14	Survival - Yeast	Kosmos 368 ('70)		(5) p. 31
C15	BIOSTACK II To study biological effects of individual heavy nuclei with high energy loss (HZE) - Protozoan cysts	Apollo 17 ('72)	Hermetically sealed aluminum container	(1) p. 167
C16	Microbial Response to Space Environment - Various	Apollo 16 ('72)	See (72)	(1) p. 172
C17	Symbiotic Growth of <i>Chlorella</i> and Kellir in Micro-Gravity (Algae & Yeast)	STS 51-G ('85)		(4) p. 96

### 3. Microorganisms (Concluded)

#	EXPERIMENT	FLOWN/PLANNED	HARDWARE	REFERENCES
18	Contraction Behaviour and Prototyping in the Slime Mould Physarum Polycephalum	Spacelab D-1 ('85)	Designed light microscope that could be mounted in the Biorack glovebox. The microscope contained 16-mm film cassettes to register the shuttle streaming and permitted the integration of the photo-diode in one ocular for registration of the radial contractions of a strand. The analogue signals of the diode were digitized by means of digitizing amplifiers. The amplifier electronics were especially developed for this Spacelab experiment.	(12) p. 55
C19	The Paramecium Experiment	Spacelab D-1 ('85)	Cells cultivated in a straw medium bacteriolysed with Aerobacter aerogenes. 10 day, postautogenous cells were isolated by cloning. The eight sister cells obtained after 3 divisions were isolated and each cell placed in a small plastic bag with 0.65 ml of culture medium. Each bag included 2 small glass ampullae filled with 30 µl of a fixative (glutaraldehyde 35% in cacodylate buffer 0.2 M) according to the techniques developed for the Cytos experiments. After welding the bags and checking cell viability, the bags were placed in culture boxes. Each box included 4 small metallic spindles, which, when rotated by a crew member, caused the glass ampullae to break. Fixative then spread out so that the whole culture was fixed within 1 or 2 minutes. Culture boxes	(12) p. 70

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## **ATTACHMENT C**

### **CELL RESEARCH HARDWARE/FACILITIES (FLOWN/PLANNED/EXISTING)**

1. Cell Research Flight Hardware
2. Groundbased NASA Facilities

# 1. Cell Research Flight Hardware

	A	B	C	D	E
	#	HARDWARE	DESCRIPTION	MISSIONS	REFERENCE
1					
2					
3	1	Woodlawn Wanderer 9	Maintained ambient temp. of bt 10 C and 35 C.	Skylab	(2) p. 222
4			Sealed to provide 1atm pressure. Internally, the package is separated into a camera-microscope section and a separately sealed growth curve experiment section. See Fig.		
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9	2.1	Blood-Kit	Consisted of a bag of Nomex containing lithium-heparin coated syringes, tourniquets, cotton-wool balls, surgical tape, wiping towels.	Biorack on Spacelab D-1	(12) p. 90
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13	2.2	Cell Culture flasks	Made of teflon/glass fiber consisted of cylindrical chambers (10 ml) sealed by a mobile piston, and were designed and developed in our laboratory. 2 such flasks fit into Type I standard Biorack expt container. Fresh blood samples and other reagents were injected (using 1ml tuberculin syringes) into the flasks through a silicon rubber septum fitted in the piston.	Biorack on Spacelab D-1	(12) p. 90
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22	2.3	Syringes	Used for injecting con A, 3H-thymidine, and glutaraldehyde, modified so that 8 would fit into a Biorack container.	Biorack on Spacelab D-1	(12) p. 90
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26	2.4	Medium	The medium (RPMI 1640, Gibco) was supplemented with 20% heat-inactivated human serum of the same blood group as the donor's, and contained 1000 I.U. heparin, 50 mg/ml gentamycin, 40mM Hepesbuffer and 5 mM sodium bicarbonate. The last 2 components permit culture growth in the absence of a controlled CO2 atmosphere in sealed flasks. Cells were stimulated by infecting con A at 50 mc/ml	Biorack on Spacelab D-1	(12) p. 91
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1. Cell Research Flight Hardware (Continued)

A #	B HARDWARE	C		D		E REFERENCE
		DESCRIPTION		MISSIONS		
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36	3	3 Type I experiment containers	A flight container (FM), a ground control container (TM) and a spare one. Each contained 4 sets of 2 bags each with 1.4 ml of cell suspension (200,000 cells/ml) and either no ampoules, 2 ampoules with fixative or 4 ampoules 2 containing fixative, and 2 with labelled Uridin on a plastic support. The plastic bags were sealed before being placed in the experiment containers. In flight, crew members broke the glass ampoules at scheduled times to release the fixative or labelled solution.	Biorack on Spacelab D-1	(12) p. 102	
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47	4	Fluid Experiments Apparatus (FEA)	Designed to provide industrial users with a convenient, low-cost, modular experiment system for fundamental space-processing research in biology, chemistry, and physics. With the FEA, investigators can conduct basic and applied processing or product development experiments in general liquid chemistry, crystal growth, fluid mechanics, thermodynamics, and cell culturing of biological materials and living organisms. This general-use, adaptable facility can be configured to manipulate a wide variety of experiments including gaseous, liquid, or solid samples, expose samples to vacuum conditions, and heat and cool samples. A number of specialized subsystems are planned for the FEA, including low-high-temperature furnaces, custom-designed heaters, special sample containers and a specimen centrifuge. These modules will allow FEA hardware and operations to be customized to support a wide range of experiment requirements.		(13) p. 4-11	
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1. Cell Research Flight Hardware (Continued)

66 #	A	B	C		D	E
			DESCRIPTION	MISSIONS		
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68	5	Refrigerator freezer	An active unit with a temperature range from -22 to +10 C. It can be used to cool blood, body fluids, and cell samples as well as solutions and fluids intended for injection. It also may be used to house small animals, to incubate amphibian zygotes and to stow animal food supplies. It is designed to accept experiment racks, shelves and containers for a variety of purposes. 2 units are available: 1 designed for the orbiter middeck and 1 for Spacelab.			
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78	6	Phase partitioning experiment apparatus (PPE)	Measures the spontaneous demixing of liquid-liquid, aqueous polymer 2-phase systems. 2 phase separation is universally used to separate biological cells and proteins. PPE permits the study of altering volume ratios, viscosity, interfacial tension, interfacial bulk phase potential, phase composition on the kinetics of demixing and the effects of chamber geometry, materials and wall coatings of the foregoing parameters. The PPE is configured to study natural coalescence and surface tension, 2 methods of phase separation. It also allows variations in interfacial tension, phase volume ratio, phase system composition and added particles. Up to 24 separate cavities can be filled with small quantities of 2 different polymers in simple water/salt solutions. The apparatus is shaken and photographed to record phase separation.			
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80					(13)	p. 4-35
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95	7	Refrigerator/incubator module	An active unit with a temperature range from 0 to +40 C. The temperature is set using a front-mounted variable potentiometer. Switching between the refrigeration and incubation modes occurs automatically			
96					(13)	p. 4-37
97						
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1. Cell Research Flight Hardware (Continued)

A	B	C	D	E
99 #	HARDWARE	DESCRIPTION	MISSIONS	REFERENCE
100				
101	8 Refrigerator/incubator module (R/IM)	Provides an easily integrated, temperature-controlled storage area for experiment samples, such as living cells, organisms and materials which must be maintained at specific temperatures in preparation for or after processing. This R/IM can be controlled to 1 degree intervals between 4 and 37.5 C.		(13) p. 4-36
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108	9 Tissue Culture incubator	Capable of maintaining 37 C ( $\pm$ 0.5 C). It can house 4 15-ml cultures. The culture chambers are made of teflon and glass and are equipped with a septum permitting the addition of material in flight via syringes also stored in the incubator. The syringes may be either modified 5-ml or standard syringes. The cultures are designed to be liquid only. Volume expansion of the culture vessels is achieved by a teflon-sleeved piston arrangement in which the septum is housed.		(13) p. 4-41
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122	10 Cell Culture Kit	A set of apparatuses, main chamber units, medium containers, waste collectors, and glutaraldehyde applicators, for mammalian cell culture experiments. The main chamber unit has 2 rooms separated by a semipermeable membrane with 2 sets of septa for medium exchanges or chemical treatments free from contamination. The oxygen concentration in the medium can be spontaneously maintained from the atmosphere. The temperature and humidity are controlled by the incubator (TEHT).	Planned for SL-J mission --Japanese	(14) p. 26
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135	11 Type I container	With the microchambers fitted with agar-coated red glass windows and a microscope. (for Slime mold Physarum Polycyphalum experiment)	Spacelab D-1	(12) p. 59
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139	12 Culture box	(see description with pictures)	Spacelab D-1	(12) p. 70-71

1. Cell Research Flight Hardware (Concluded)

A	B		C		D	E
	140 #	HARDWARE	DESCRIPTION	MISSIONS		
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142	13	Free Flow Electrophoresis Unit (FFEU)	A continuous flow type electrophoresis equipment developed for the charged material separations under conditions of microgravity. The separation chamber has been modified to be much thicker compared to ground use equipment, because there are no restrictions of thermal convection or sedimentation phenomena. The system is equipped with a dedicated microprocessor for operations and environmental controls as well as data processing. The sample separation can be monitored by a real-time, multichannel detector directly coupled with the electrophoresis chamber.	Spacelab J-1	(14) p. 26 (pics)	
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157	14	Thermoelectric Incubator (TEI)	Developed for Spacelab experiments as a fundamental tool for life sciences. Both temperature and humidity are regulated at preset values.	Spacelab J-1	(14) p. 30(pics)	
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GROUND BASED FACILITIES			
NAME	DESCRIPTION	YEAR	REFERENCE
Bioprocessing/Cell Biology Research Laboratory (CBRL)	Used for the culturing of cells for separation in ground-based and Space Shuttle flight experiments, evaluation of enzymes produced by separated cell subpopulations, evaluation of attachment of cells to substrata in micro-gravity, development of experiments to evaluate the effects of space environment on cells, development of a bioreactor capable of operating in a microgravity environment, and preparation of cells for bioreactor studies. SUPPORTS: Cell biology and tissue culture research, cell production, and evaluation in support of Space Shuttle and Space Station experiments, design and construction of a space prototype bioreactor.	1979	(15) p. 6.2-5
Cytometry Lab.	Digitizes cell images for the analysis of biomedically important changes such as gross cell damage, chromosome breaks, or changes in cell age and type. Fluorescent tagged cells may be identified, sorted, and recultured for further analysis as required (for example, in cell cycle analyses and the study of anomalies in the immune mechanism or in red blood cell production). SUPPORTS: Electro-optical digitization of cell images and fluorescent-activated flow cytometry.	1973	(15) p. 6.2-9



**ATTACHMENT D**

**REFERENCES**

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## LIST OF REFERENCES FOR ATTACHMENT B

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